MIKE SHE for integrated surface water – groundwater modeling

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DHI Water & Environment

MIKE SHE

an Integrated Hydrological Modelling System

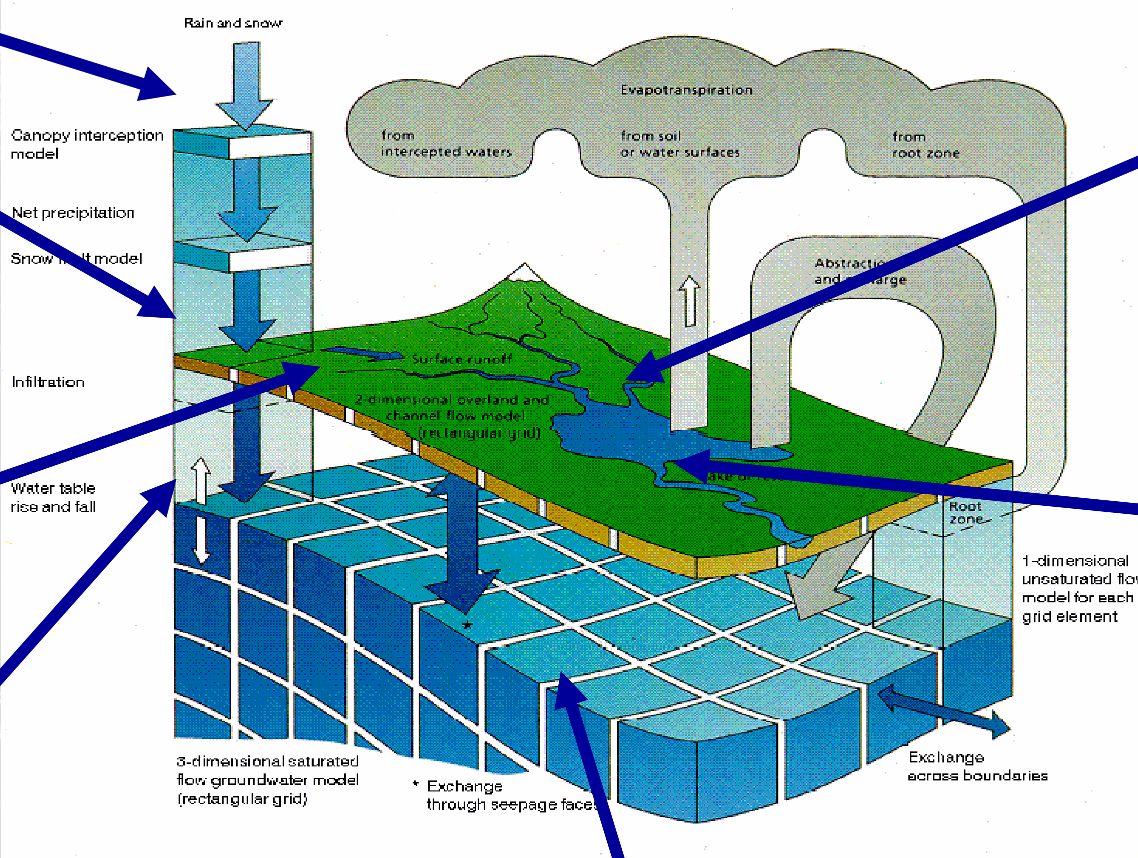
that covers the entire land phase of the hydrologic cycle

Precipitation and snowmelt

Vegetation based evapotranspiration and infiltration

Demand driven irrigation

Unsaturated groundwater flow



Channel flow in rivers and lakes

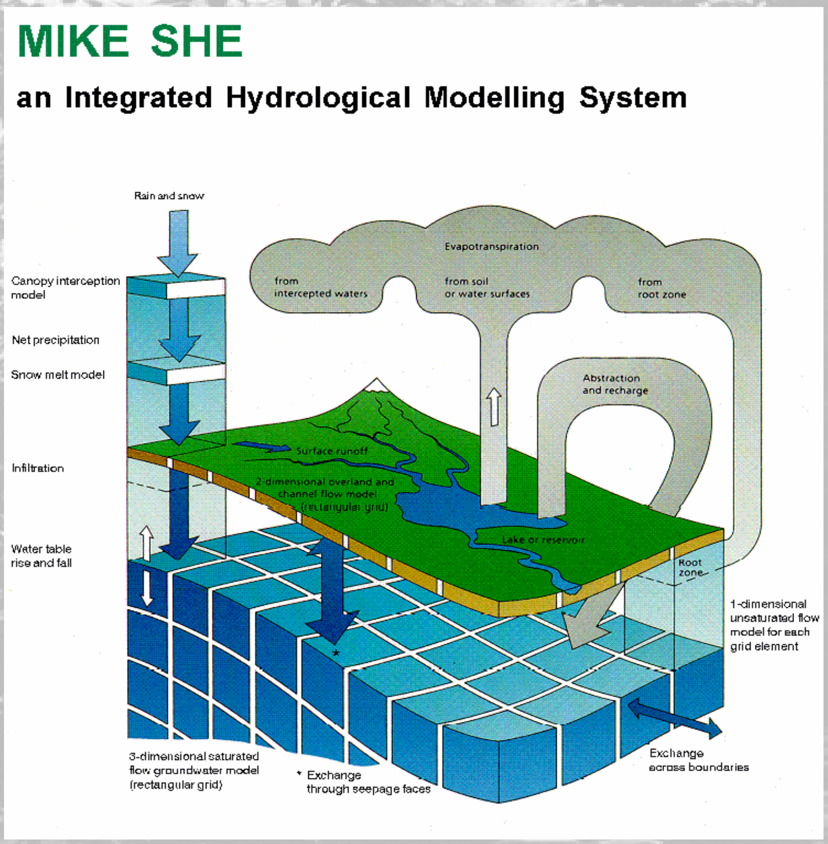
Overland surface flow and flooding

Saturated groundwater flow

Solute Transport

MIKE SHE

Flexible Process Descriptions



MIKE SHE in 1990

Physically based process descriptions

= conservation of mass and momentum

CHANNEL FLOW
- ⇨ 1D diffusive wave

OVERLAND FLOW
- ⇨ 2-D diffusive wave

EVAPOTRANSPIRATION
- ⇨ Kristensen & Jensen

UNSATURATED ZONE FLOW
- ⇨ Full 1D Richards Equation

SATURATED ZONE FLOW
- ⇨ 3D Darcy flow

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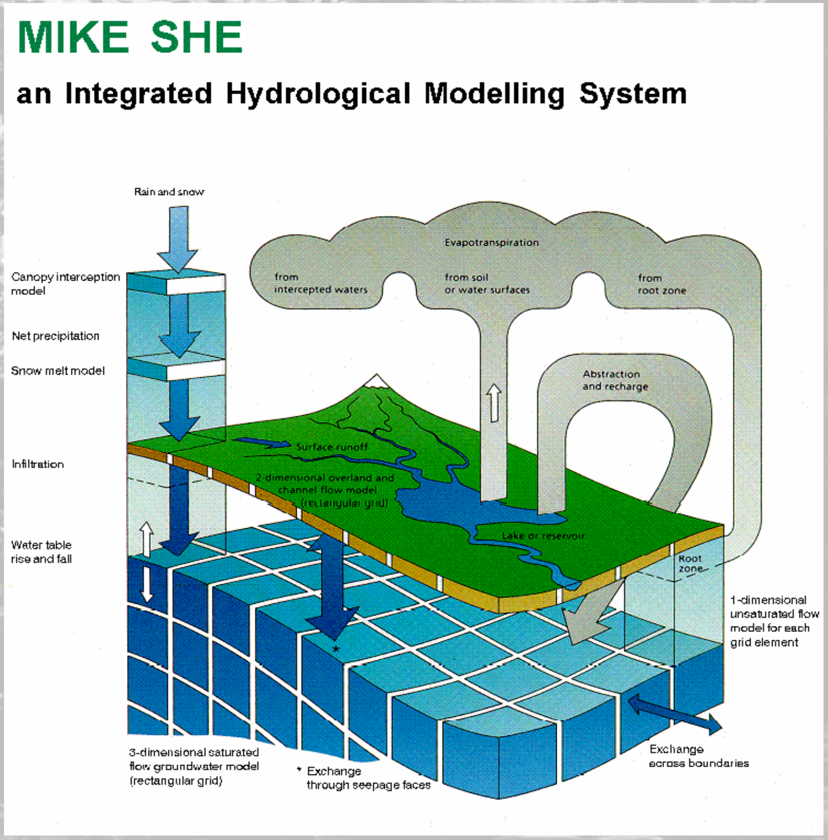
Flexible Process Descriptions



MIKE SHE in 1990

Physically based process descriptions

= conservation of mass and momentum

= physically meaningful model parameters

Physically based process descriptions are rarely required for all processes

Typically one process dominates the problem

For example:

- flood forecasting (river flows),
- nitrate pollution of groundwater (unsaturated flow and vegetation)
- wetland restoration (saturated flow and overland flow)

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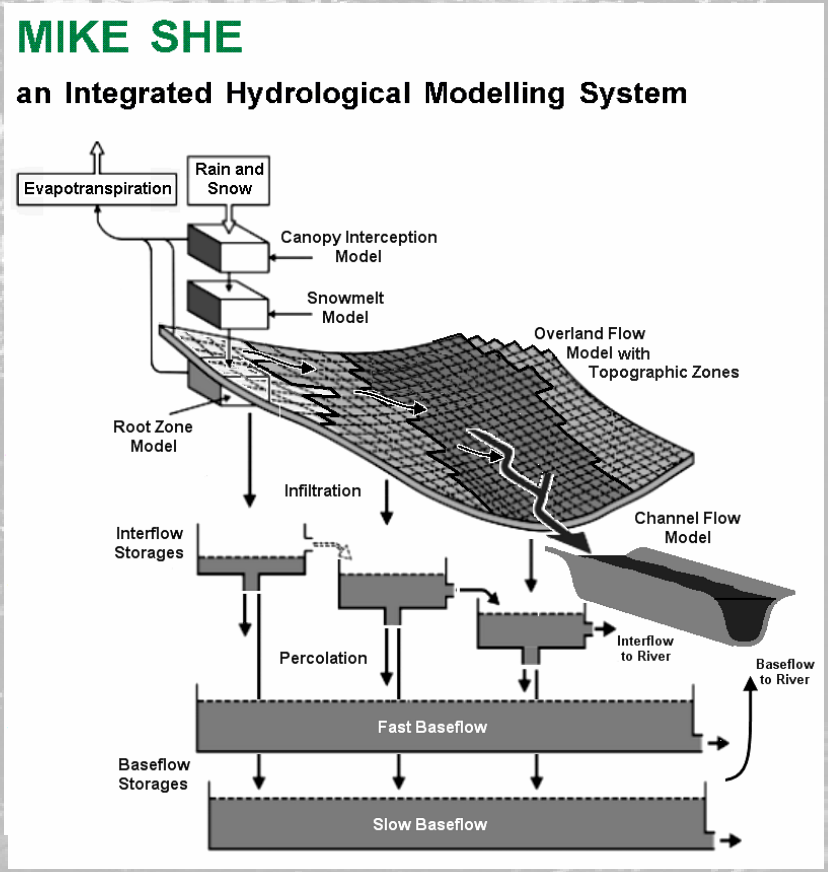
Flexible Process Descriptions



MIKE SHE in 2005

Additional conceptual based process descriptions

= lumped parameter approaches

= fewer parameters to calibrate

= less data required

= faster simulation times

But, parameters are no longer physically grounded

A useful engineering tool for:

- regional basin-wide models
- models where single processes dominate
- models with sparse or no calibration data
- screening level models

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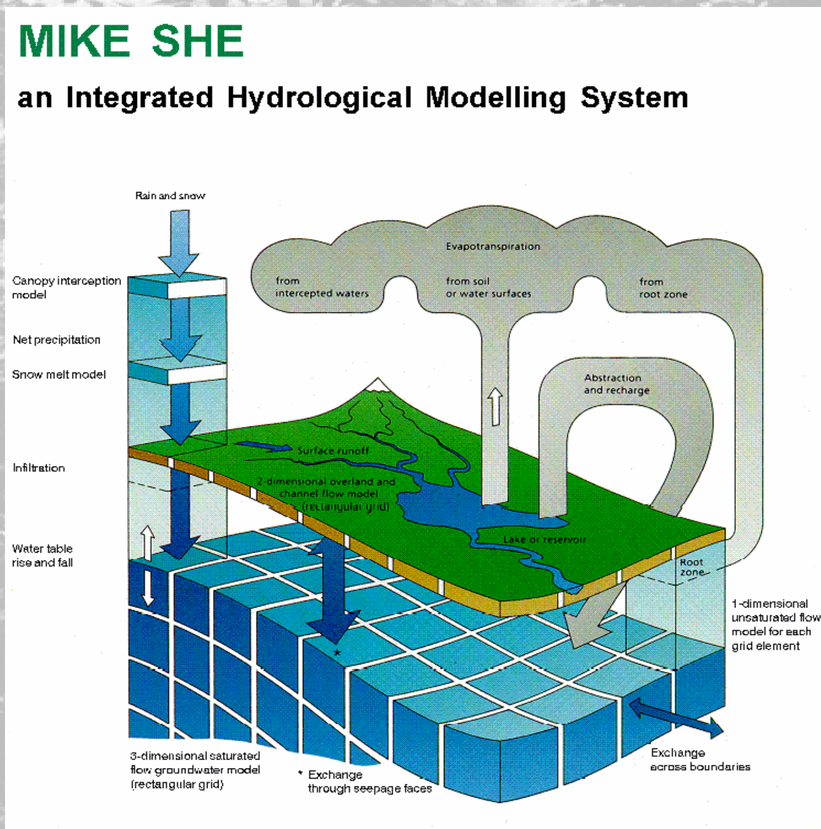
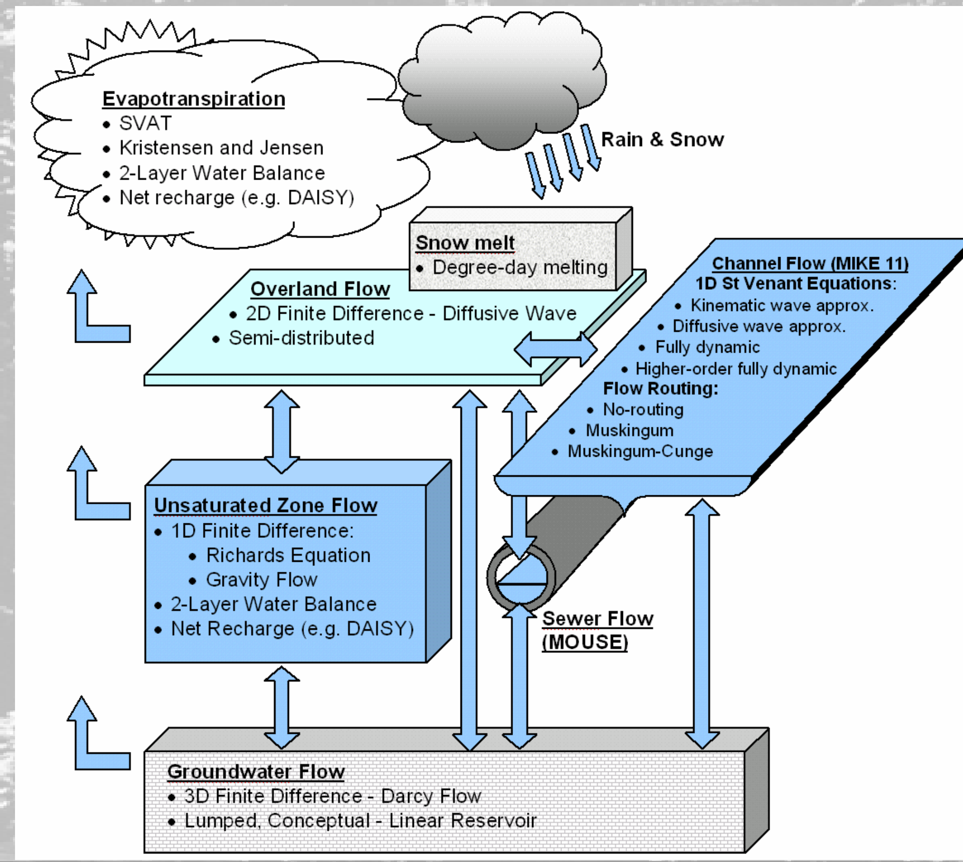
Flexible Process Descriptions

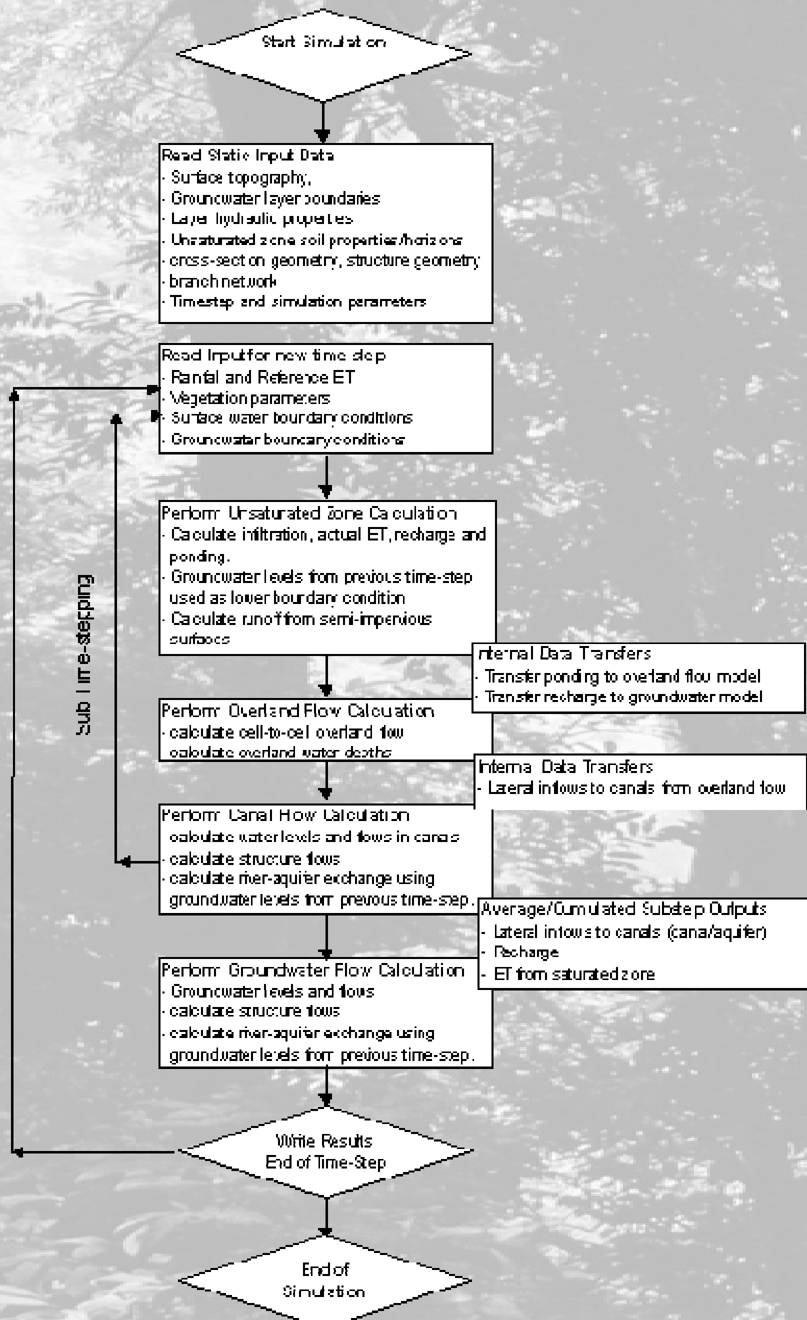




Processes can be mixed as required

Processes run on different spatial scales

Processes run on different time scales


Start Simulation
Read Static Input Data
- Surface topography,
- Groundwater layer boundaries
- Layer hydraulic properties
- Unsaturated zone soil properties/horizons
- cross-section geometry, structure geometry
- branch network
- Timestep and simulation parameters
Read Input for new time step
- Rainfall and Reference ET
- Vegetation parameters
- Surface water boundary conditions
- Groundwater boundary conditions
Perform Unsaturated Zone Calculation
- Calculate infiltration, actual ET, recharge and ponding.
- Groundwater levels from previous time-step used as lower boundary condition
- Calculate runoff from semi-impervious surfaces
Internal Data Transfers
- Transfer ponding to overland flow model
- Transfer recharge to groundwater model
Perform Overland Flow Calculation
- calculate cell-to-cell overland flow
- calculate overland water depths
Internal Data Transfers
- Lateral inflows to canals from overland flow
Perform Canal Flow Calculation
- calculate water levels and flows in canals
- calculate structure flows
- calculate river-aquifer exchange using groundwater levels from previous time-step.
Average/Cumulated Substep Outputs
- Lateral inflows to canals (canal/aquifer)
- Recharge
- ET from saturated zone
Perform Groundwater Flow Calculation
- Groundwater levels and flows
- calculate structure flows
- calculate river-aquifer exchange using groundwater levels from previous time-step.
Sub Time-stepping
Write Results
End of Time-Step
End of Simulation

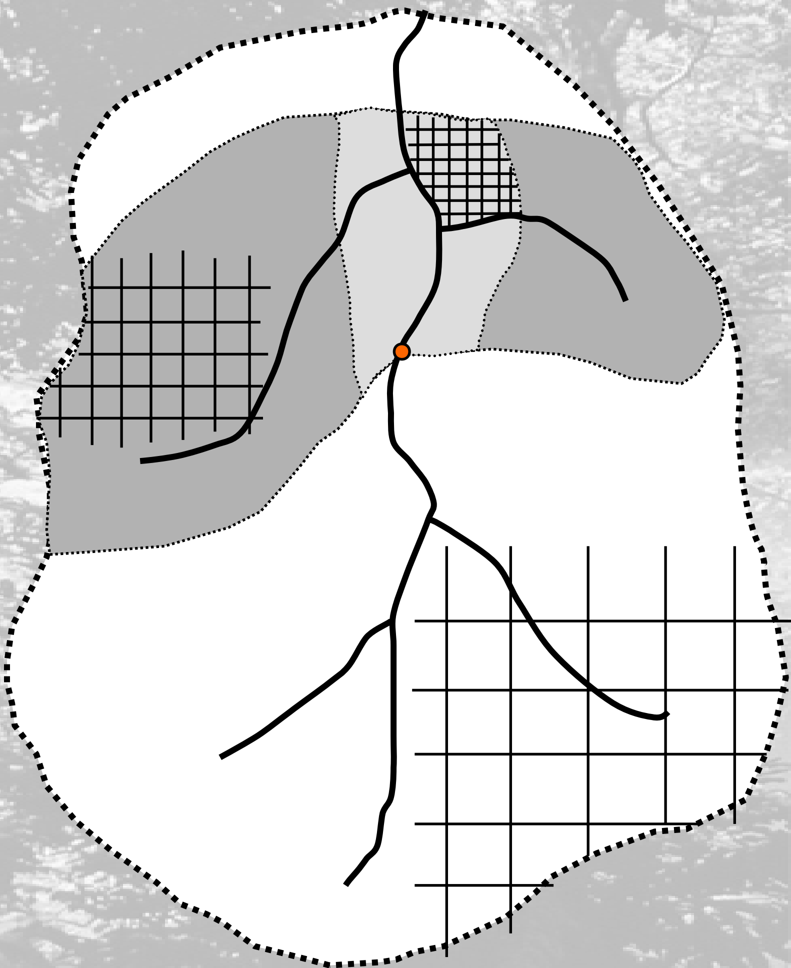
MIKE SHE
Application Scales

Spatial scales

⇨ basin > watershed > field scale
⇨ cell size typically from 25-2000 m (100-6000 ft)
⇨ telescopic mesh refinement

Temporal scales

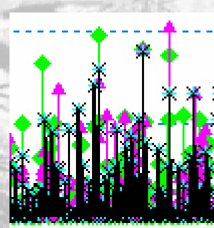
⇨ solves each model component with different computational time steps
⇨ time steps typically range from minutes for river to days for groundwater
⇨ automatic time step control



MIKE SHE – tools and GUI

Data management tools in MIKE SHE

Time Series Data



Databases

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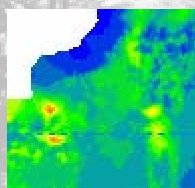
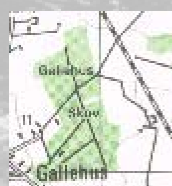
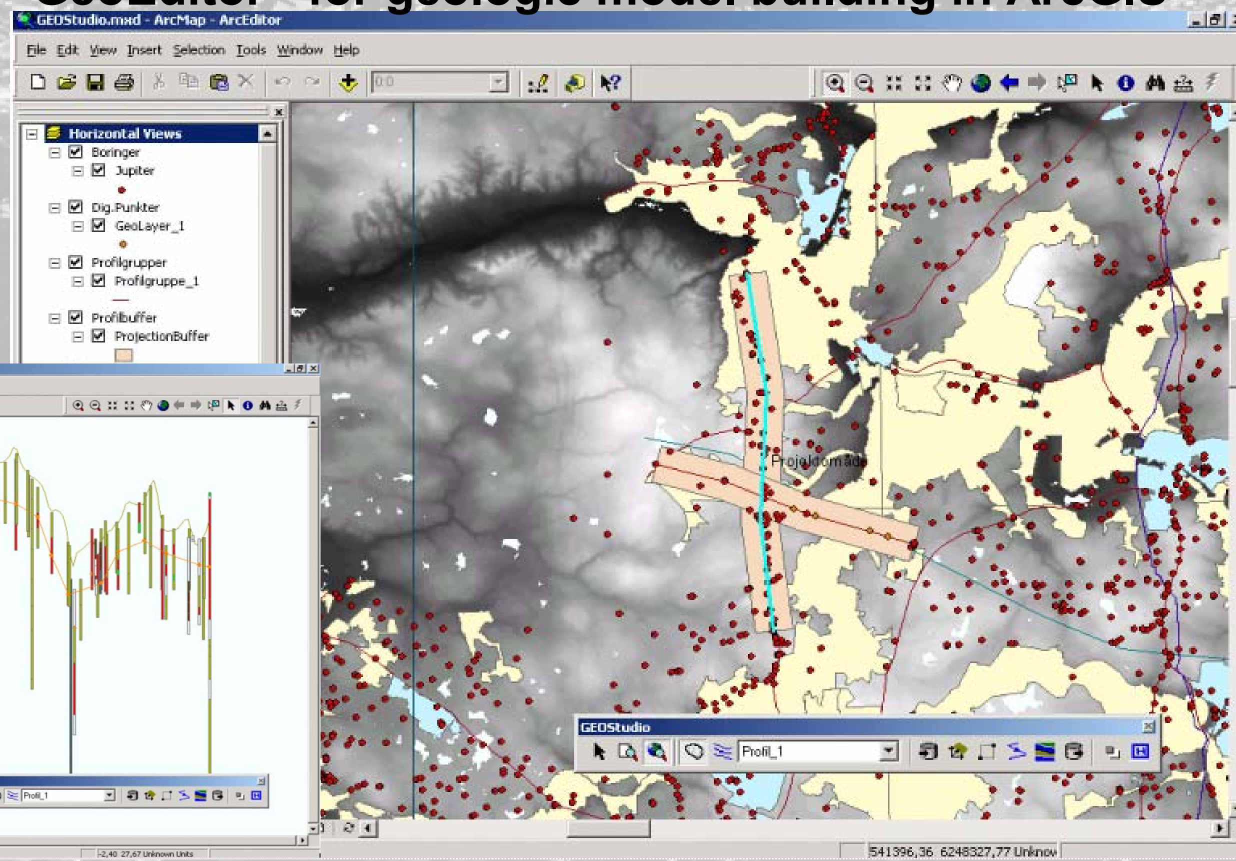
Gridded Data

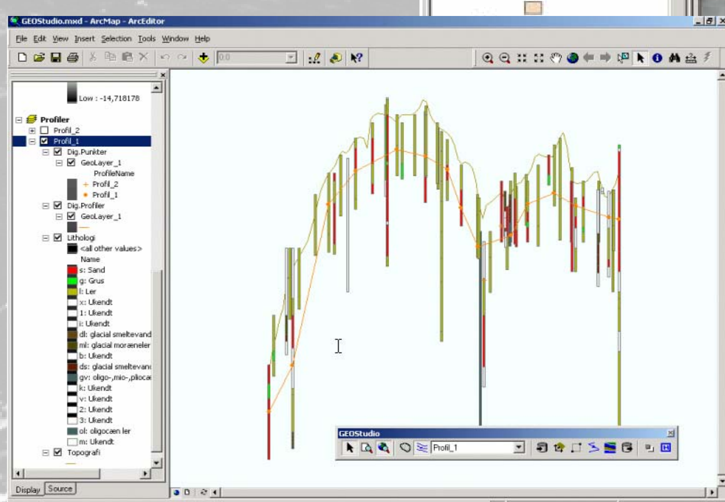


GIS/map Data



GeoEditor - for geologic model building in ArcGIS





MIKE SHE – tools and GUI

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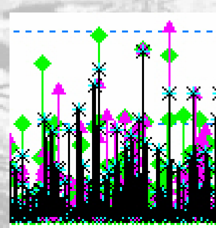
Data management tools in MIKE SHE

Time Series Data



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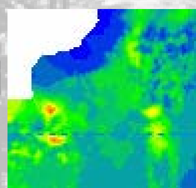
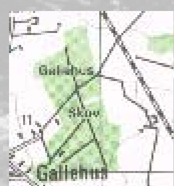
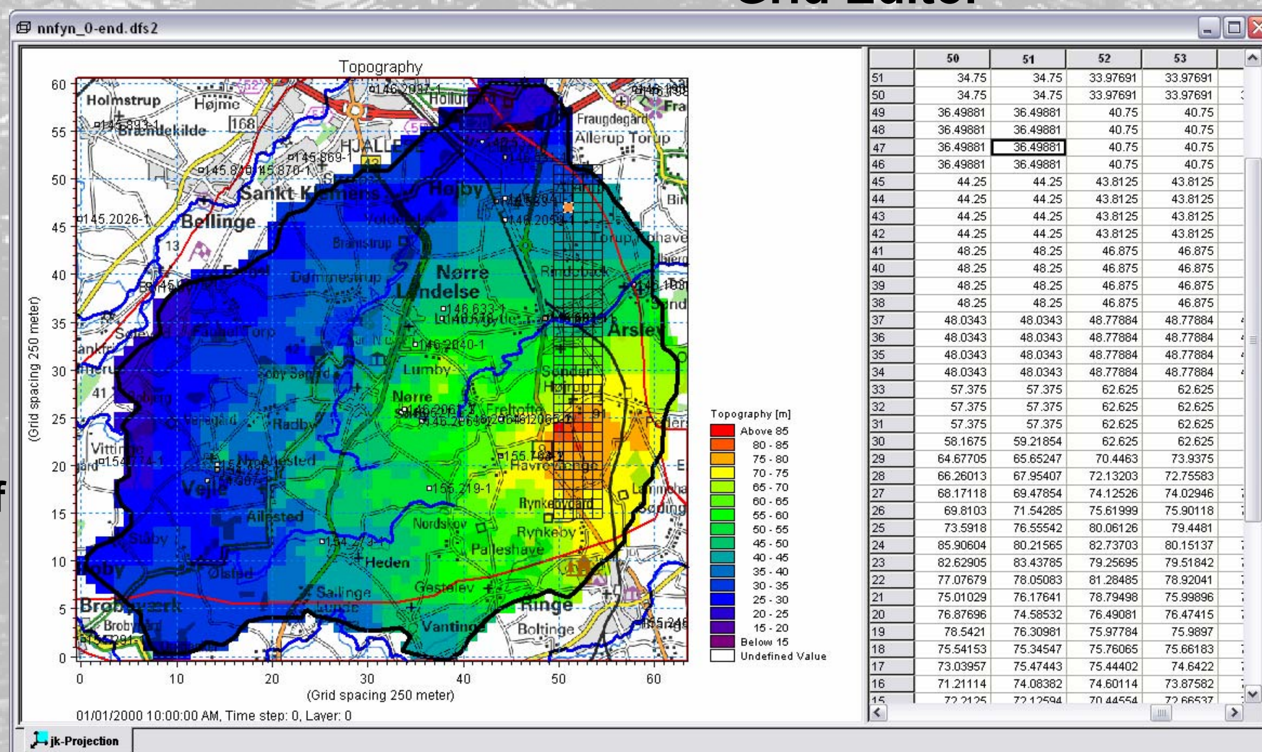


GIS/map Data



Grid Editor

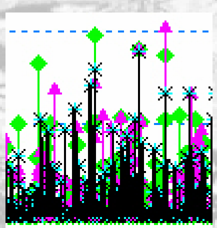


- ➔ both graphical and logical cell selection,
- ➔ tabular and global editing of values,
- ➔ data statistics,
- ➔ data operators (+, -, x, etc.)
- ➔ gridded time series

MIKE SHE tools and GUI

Data management tools in MIKE SHE

Time Series Data



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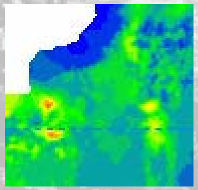

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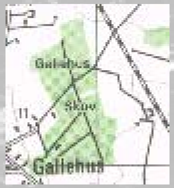

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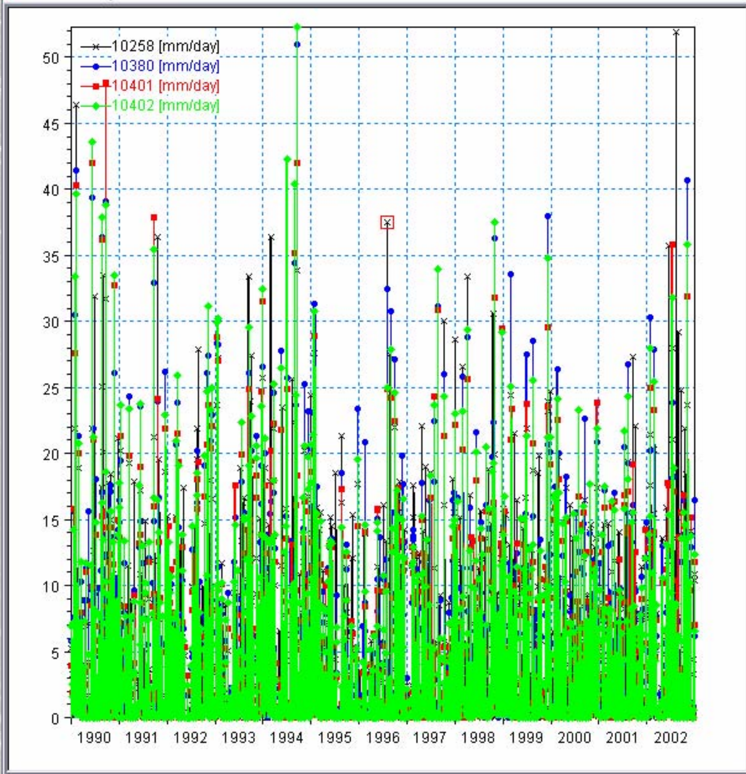
Time Series Editor

rainfall equ.dfs0



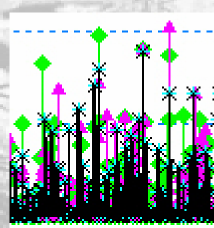
	Time	10258 [mm	10380 [mm	10401 [mm	10402 [mm
2374	02/07/1996 0	0.22	0.99	1.1	0.66
2375	03/07/1996 0	0.77	0.33	1.32	0.11
2376	04/07/1996 0	16.06	5.61	5.39	6.6
2377	05/07/1996 0	7.92	10.45	9.57	10.78
2378	06/07/1996 0	0.11	0	0	0
2379	07/07/1996 0	0	0.11	0	0
2380	08/07/1996 0	0.66	0.44	1.32	0.33
2381	09/07/1996 0	0.88	0	0.33	0.66
2382	10/07/1996 0	0	0	0	0
2383	11/07/1996 0	0	0	0	0
2384	12/07/1996 0	0	0	0	0
2385	13/07/1996 0	0	0	0	0
2386	14/07/1996 0	0.22	0	0	0
2387	15/07/1996 0	0	0	0	0
2388	16/07/1996 0	0	0	0	0
2389	17/07/1996 0	0	0	0	0
2390	18/07/1996 0	0	0	0	0
2391	19/07/1996 0	0	0	0	0
2392	20/07/1996 0	0	0	0	0
2393	21/07/1996 0	0	0	0	0
2394	22/07/1996 0	0	0	0	0
2395	23/07/1996 0	0	0	0	0
2396	24/07/1996 0	0	0.55	0.33	0.77
2397	25/07/1996 0	2.31	4.07	1.1	4.84
2398	26/07/1996 0	0	0	0	0
2399	27/07/1996 0	0.11	0	0.11	0
2400	28/07/1996 0	13.42	11.99	10.01	9.57
2401	29/07/1996 0	0	0	0	0
2402	30/07/1996 0	1.54	0.55	0.55	0.44
2403	31/07/1996 0	0	0	0	0.11
2404	01/08/1996 0	0.66	0.55	0.22	0.44
2405	02/08/1996 0	0.11	2.2	2.31	5.06
2406	03/08/1996 0	0	0	0	0
2407	04/08/1996 0	0	0	0	0
2408	05/08/1996 0	0	0	0	0
2409	06/08/1996 0	0	0	0	0
2410	07/08/1996 0	0	0	0	0
2411	08/08/1996	37.51	32.45	24.86	24.97
2412	09/08/1996 0	0	0	0.88	0.22

- ➔ graphical and logical point selection
- ➔ tabular and global editing of values
- ➔ data statistics
- ➔ data operators
- ➔ gap filling and interpolation

MIKE SHE tools and GUI

Data management tools in MIKE SHE

Time Series Data



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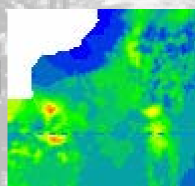
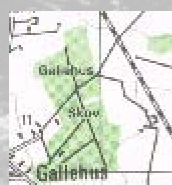
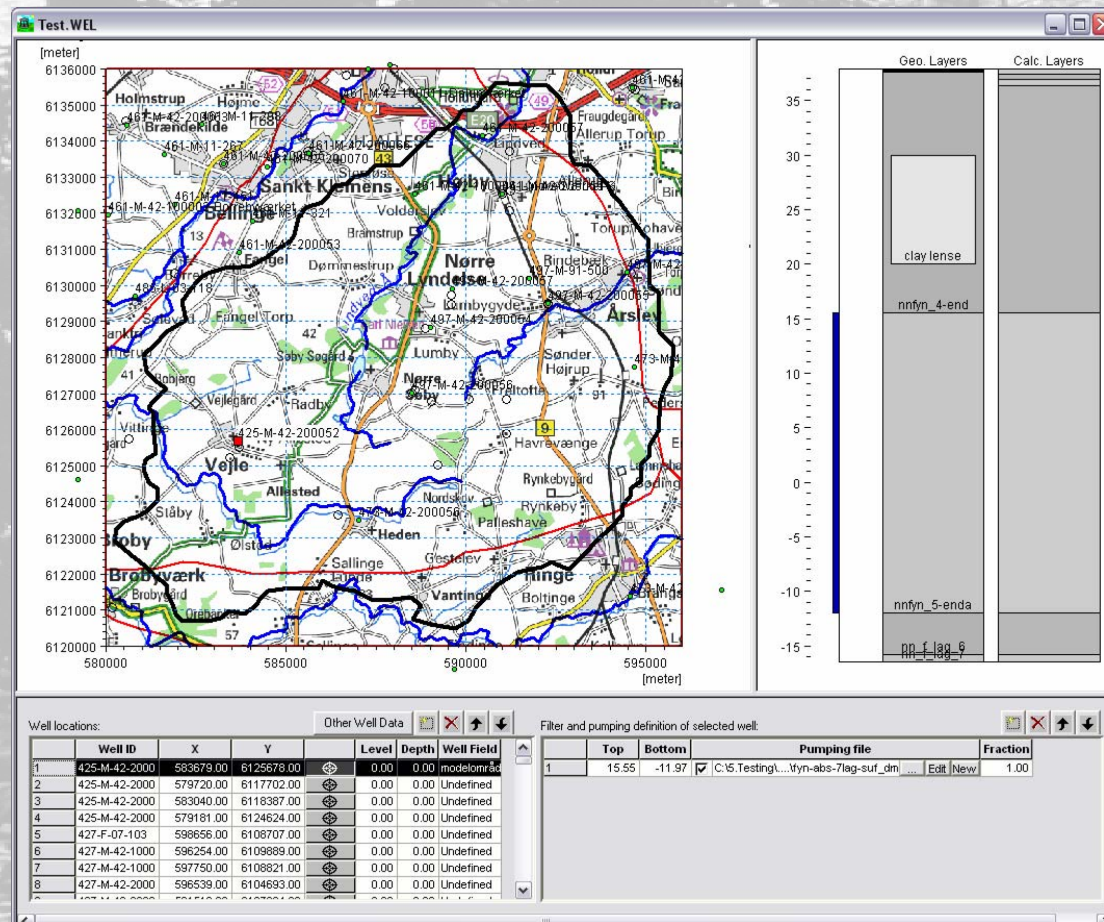


GIS/map Data



Well Database



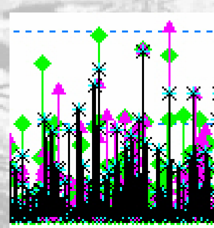
- ➔ Soils Database - for unsaturated soil properties
- ➔ Vegetation Database - for vegetation properties
- ➔ Well Database - for borehole and pumping data

MIKE SHE tool and GUI

DHI Software

WATER & ENVIRONMENT

Time Series Data



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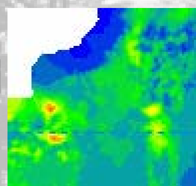
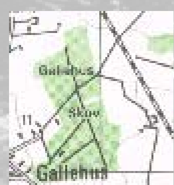
MIKE 11 (Surface Water)

Gridded Data

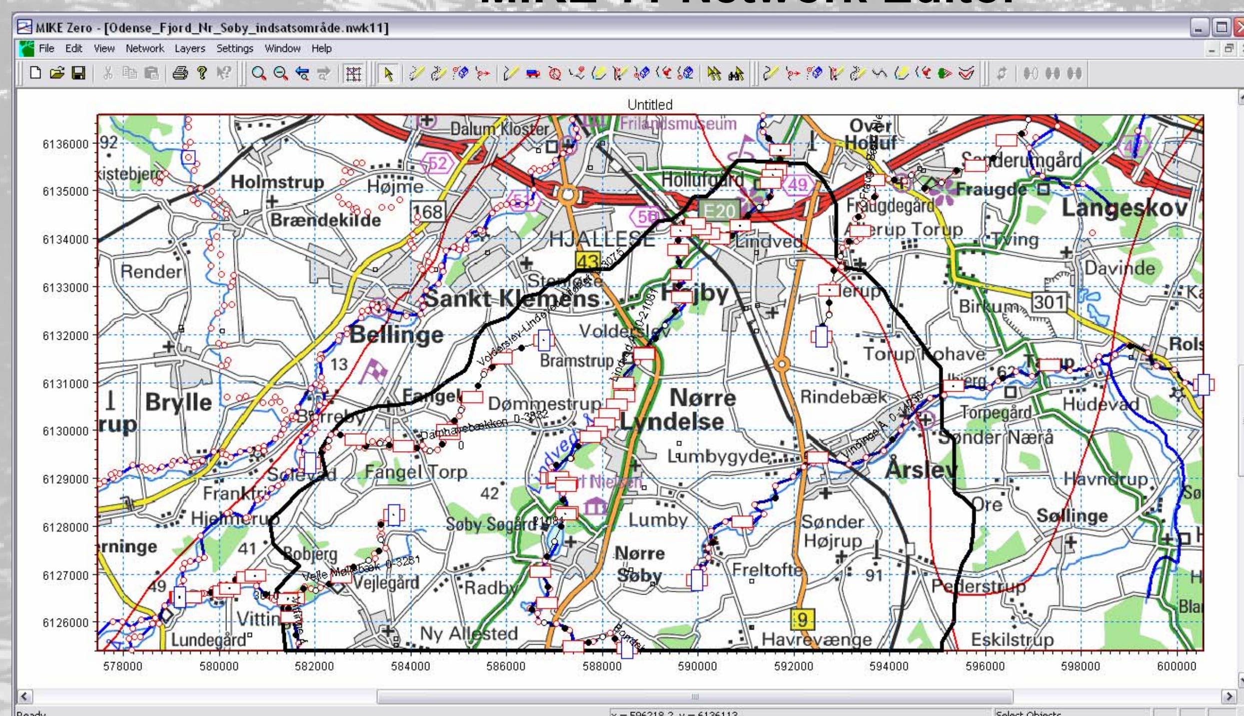


Mouse (Sewers)

GIS/map Data

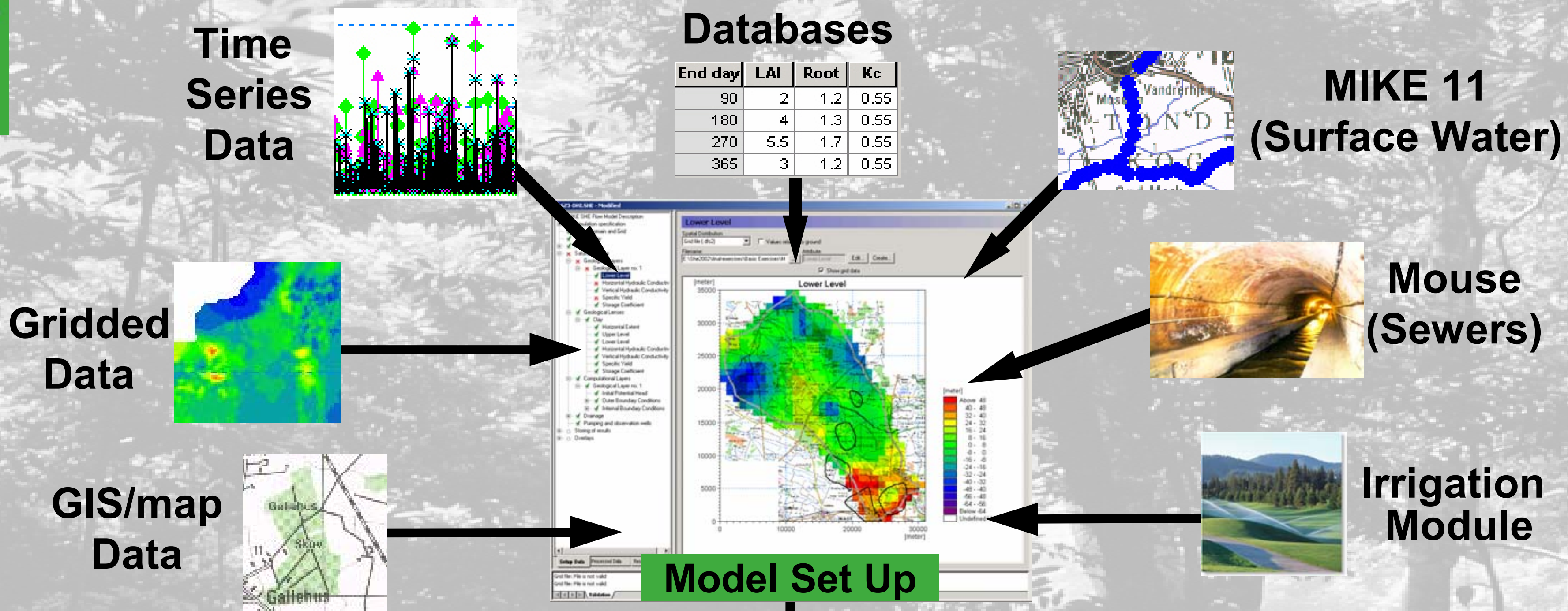


MIKE 11 Network Editor



- ➔ Surface Water
  - linked to MIKE 11 GUI
- ➔ Urban infrastructure, such as pipes and sewers
  - linked to MOUSE GUI

MIKE SHE data & model



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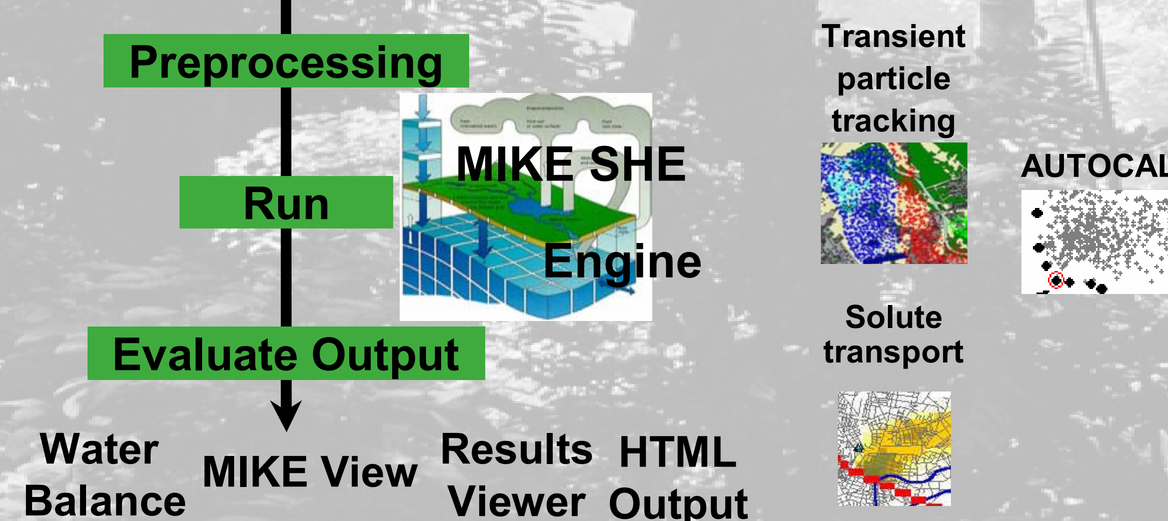
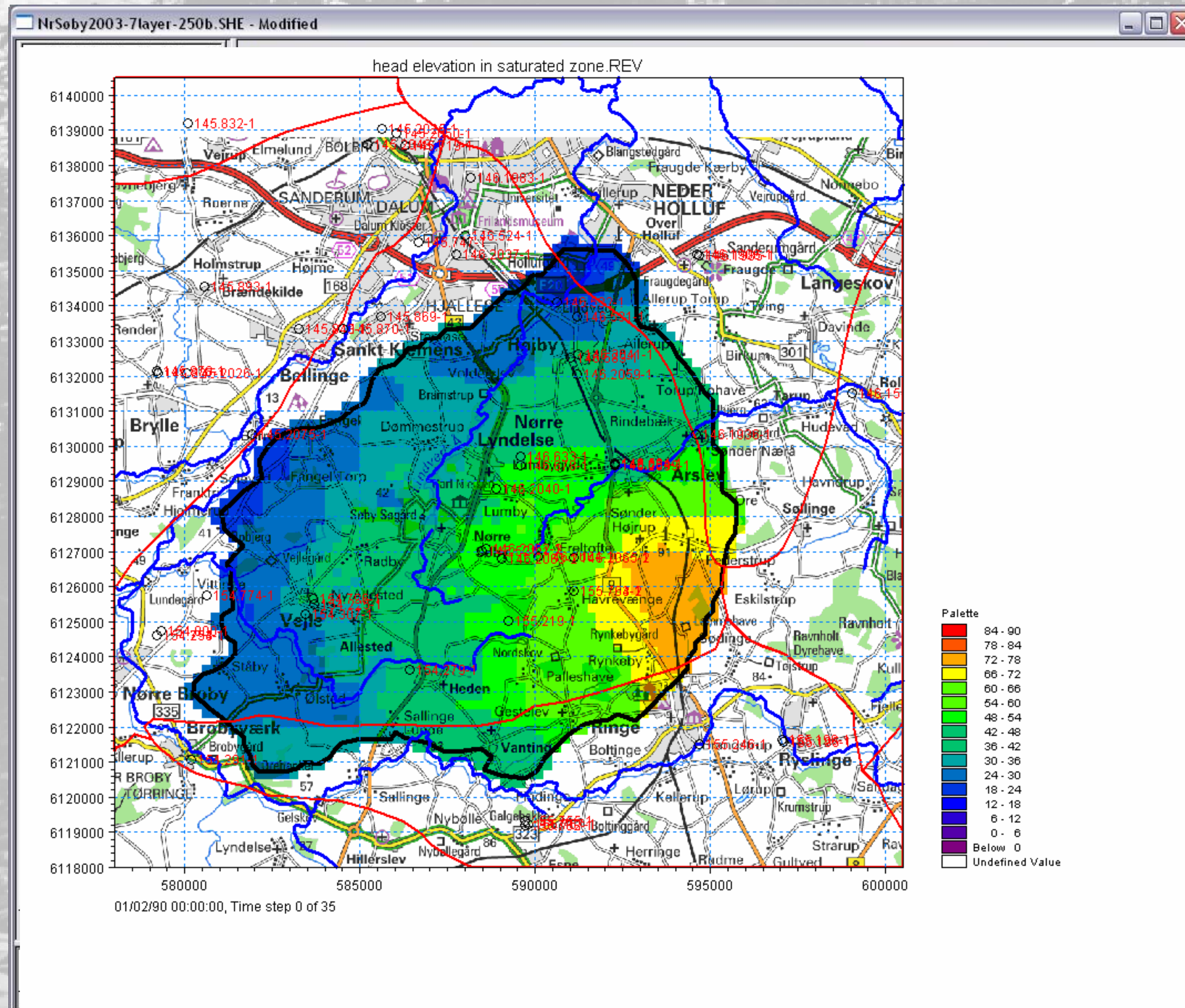


- Model independent data entry
- Numerical model generated at run time
- Comprehensive output tools
- Full water balance accounting

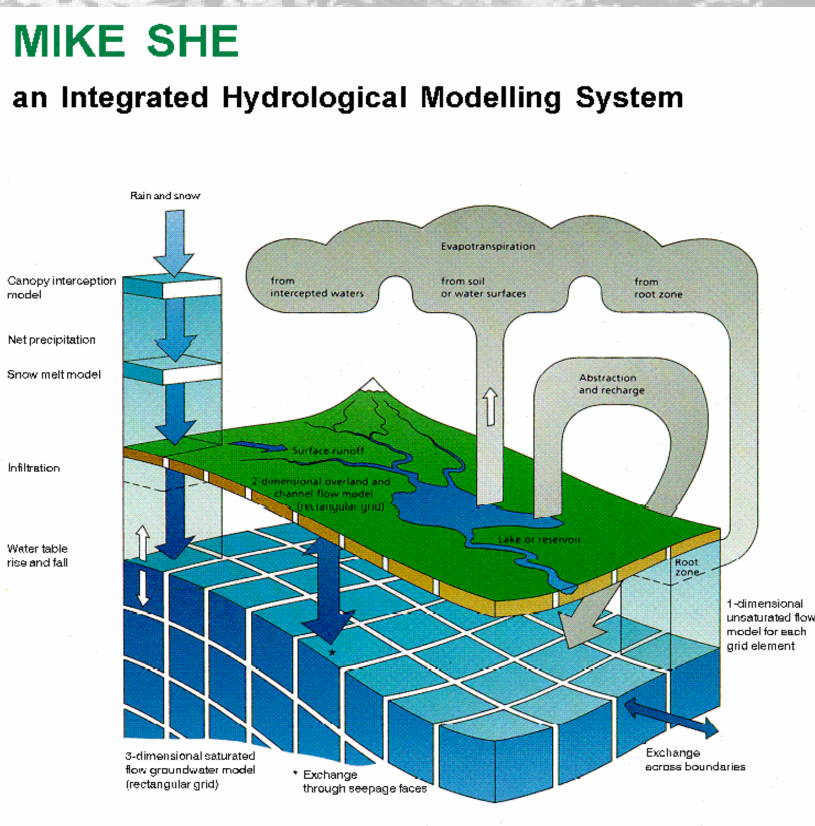
MIKE SHE
Model Results

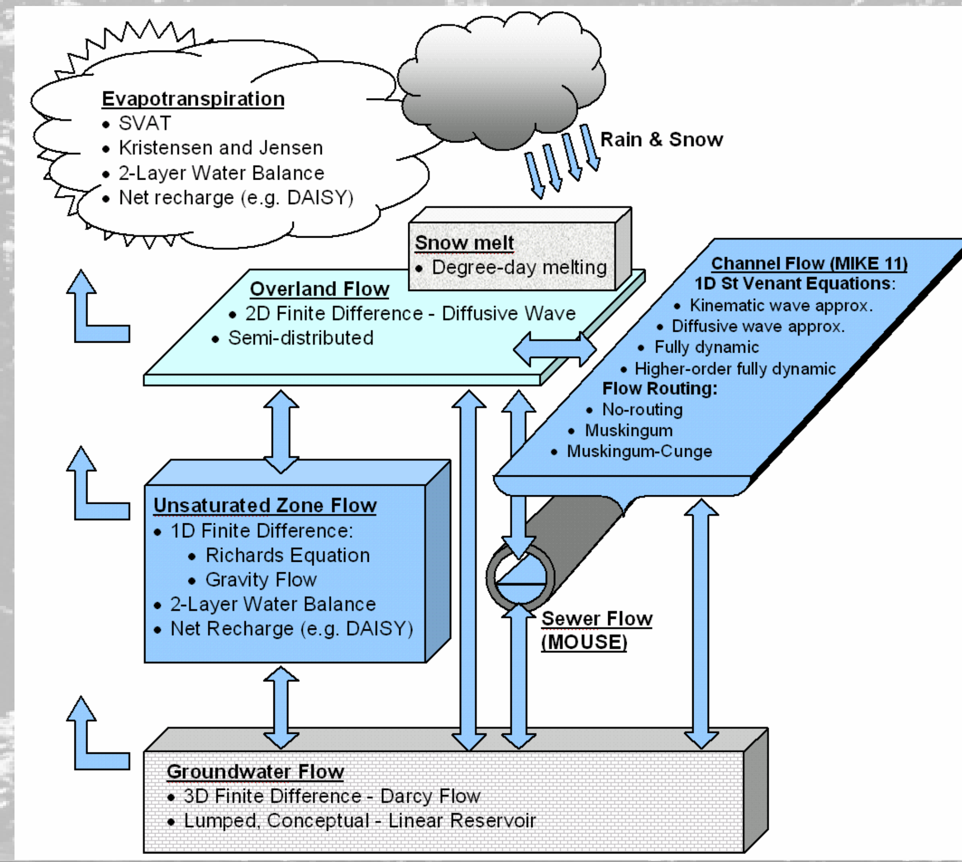
- Dynamic HTML output
- Complete water balance accounting
- Integrated animation functions
- Simultaneous 1D, 2D and 3D output



MIKE SHE

Modules and Process descriptions



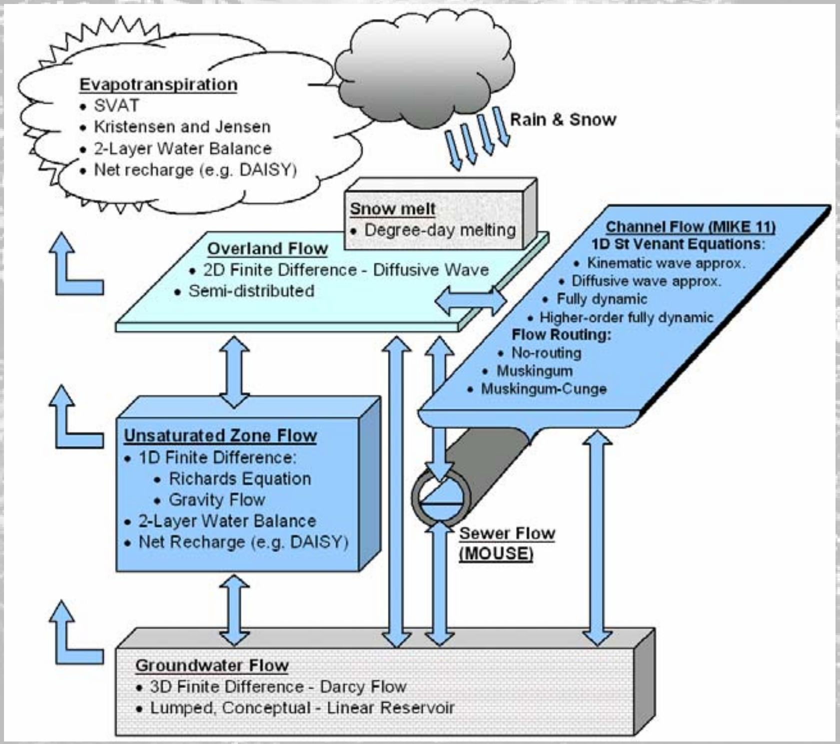


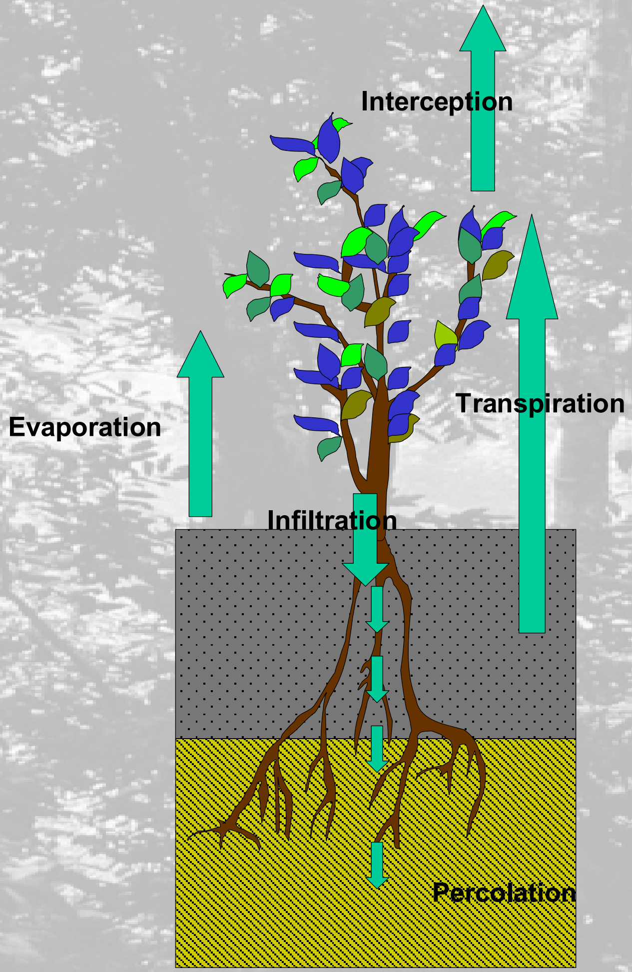
Processes can be mixed as required

Processes run on different spatial scales

Processes run on different time scales

MIKE SHE – ET component





Processes simulated by MIKE SHE 2004:

Interception of rainfall by the canopy (LAI, Cint)

Drainage from the canopy (LAI, Cint)

Evaporation from the canopy surface (LAI, Cint, Etpot)

Evaporation from ponded Water (ETpot)

Soil evaporation, f(Θ, Θwp, Θres)

Transpiration from the root zone, f(RDF, Θ, Θfc , Θw)

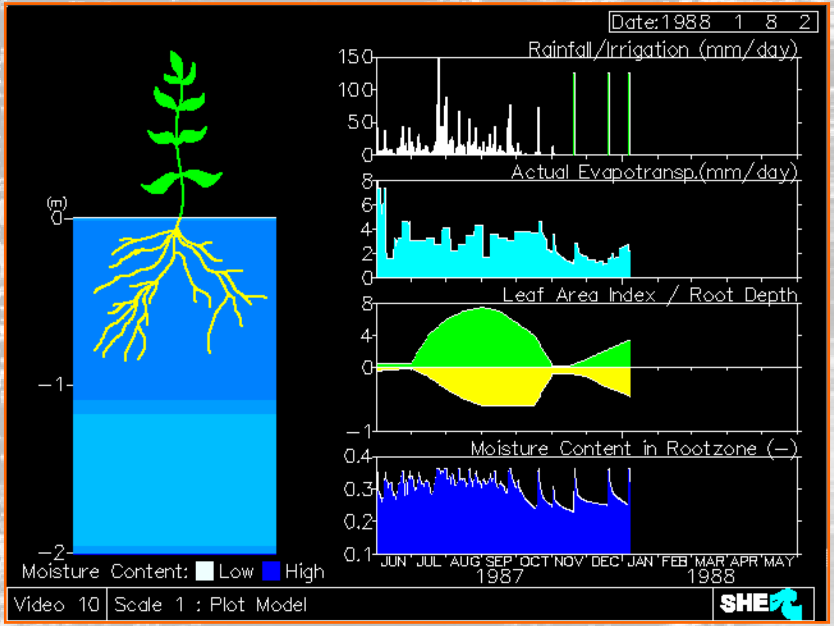
MIKE SHE - ET Calculation

ET actual = ET canopy + ET transpiration + ET pond + ET soil

Kristensen and Jensen

Empirical model calculating actual ET as a fraction of Reference ET, as a function of :

- **Vegetation characteristics (LAI and RD)**
- **actual soil water content for in the root zone**
- **ground water table - transpiration losses directly from the ground water if the root zone extends into the saturated zone**

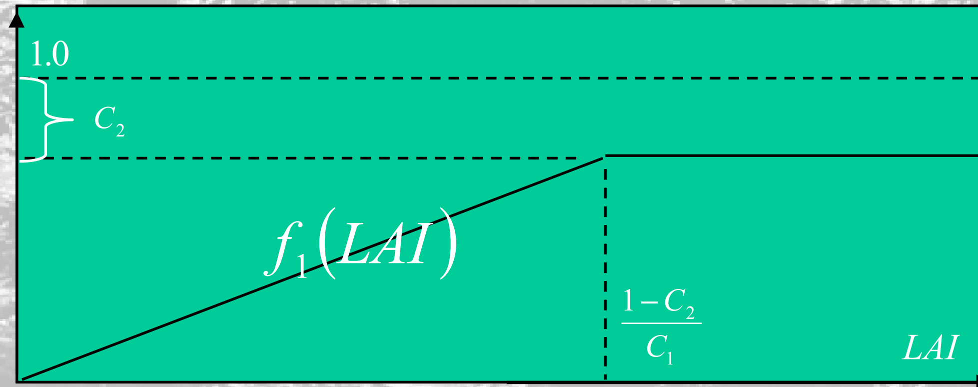


MIKE SHE ET - Kristensen & Jensen

ET actual = ET canopy + ET transpiration + ET pond + ET soil

ET Canopy

Imax = Cint * LAY
Cint: mm



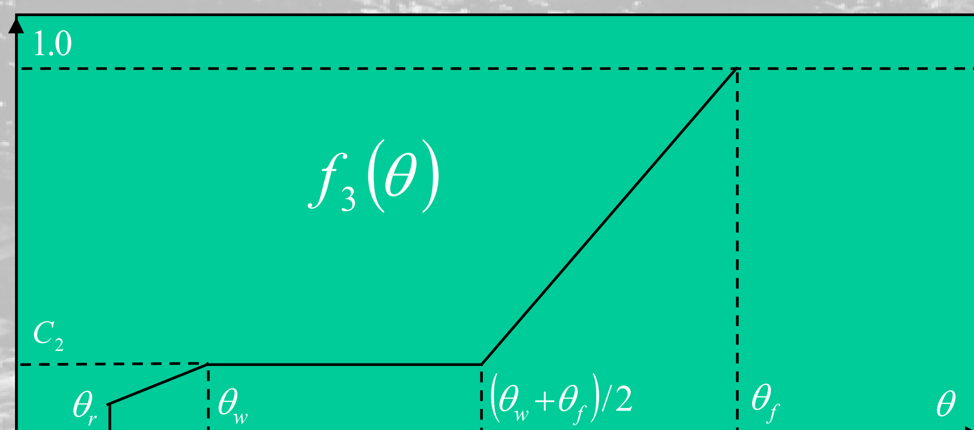
Transpiration

$$E_{at} = f_1(LAI)\, f_2(\theta)\, RDF\, E_P$$

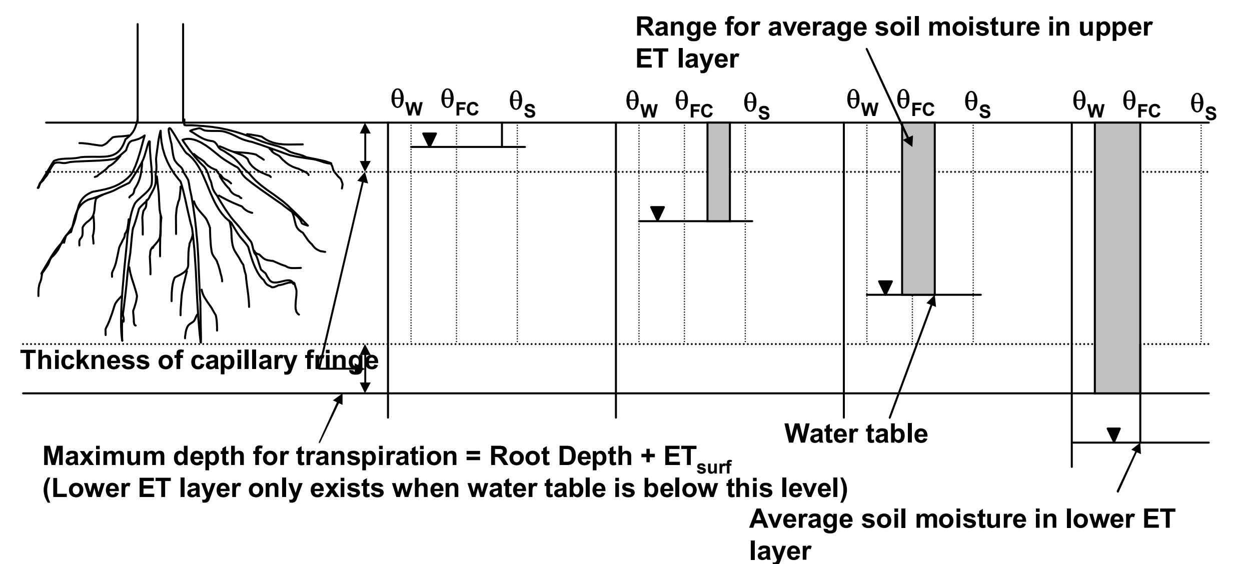
$$f_2(\theta) = 1 - \left(\frac{\theta_F - \theta}{\theta_F - \theta_W}\right)^{\frac{C_3}{E_p}}$$

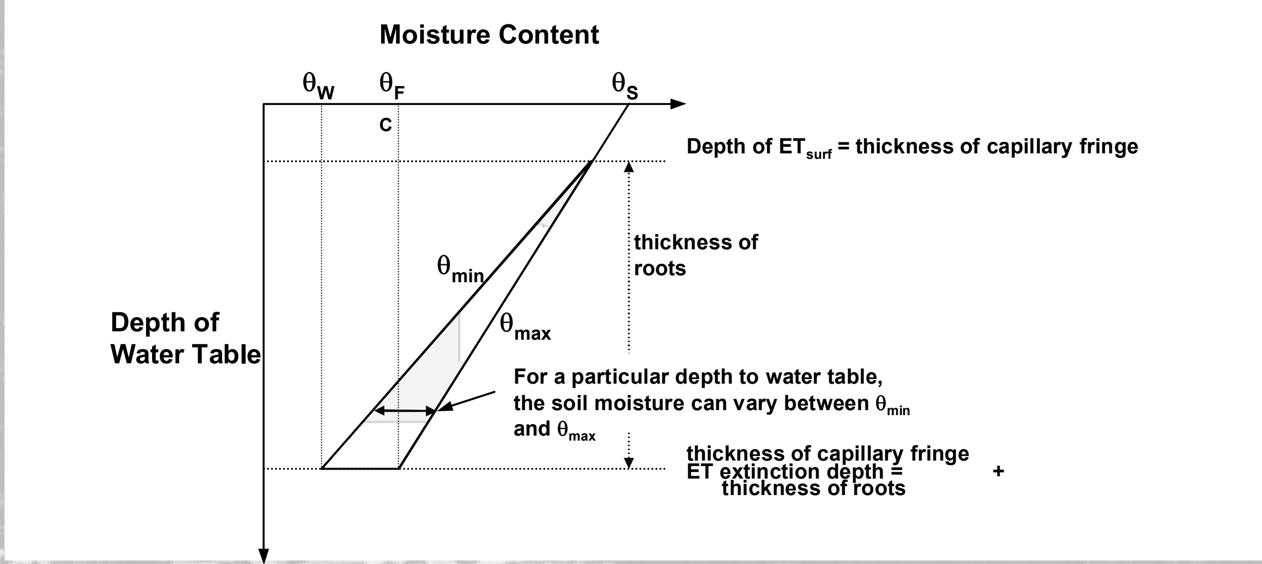
Potential ET soil

$$E_s = f_3(\theta) E_P$$



MIKE SHE ET - 2 Layer Water Balance



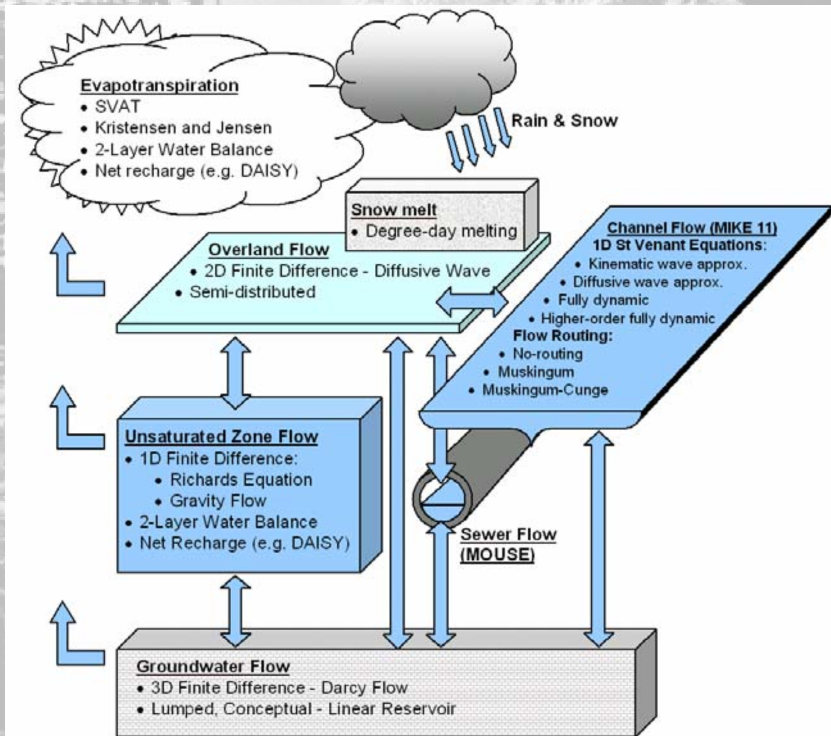


Qmax = max water content as a function of depth = MODFLOW

Qmin = min water content as function of depth

Moisture deficit = Qmax - Qmin

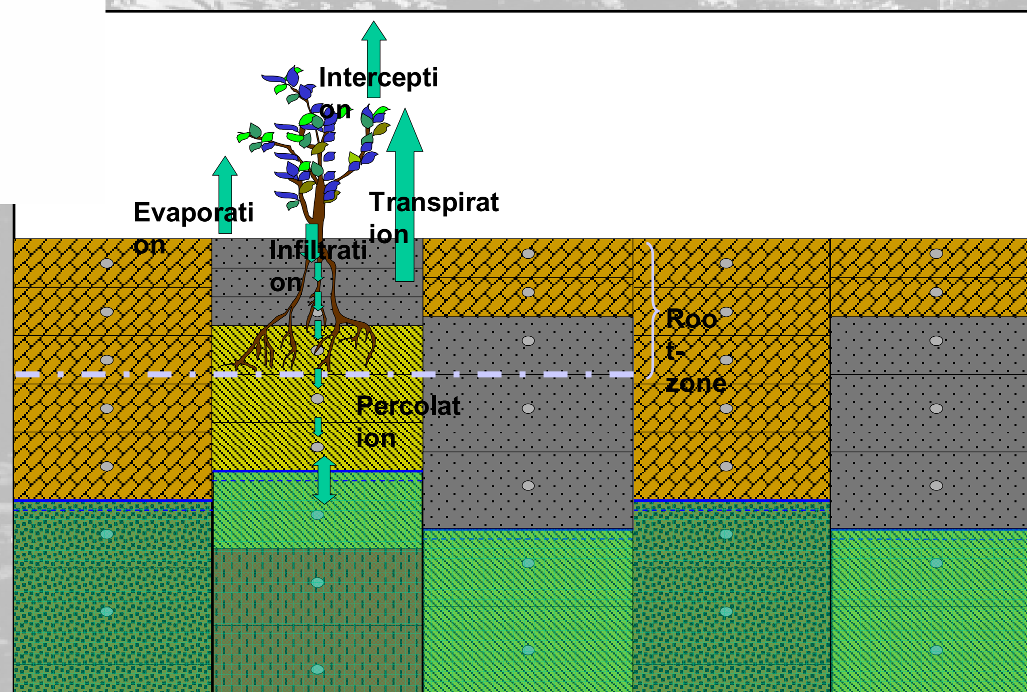
MIKE SHE UZ - the unsaturated zone



One dimensional unsaturated zone flow :

$$C\frac{\partial \psi}{\partial t} = \frac{\partial}{\partial z}\left(K\frac{\partial \psi}{\partial z}\right) + \frac{\partial K}{\partial z} - Q$$

$\psi(z,t)$	:	capillary pressure head (m)
$K(\theta)$	:	hydraulic conductivity (m/s)
θ	:	soil moisture content
Q	:	volumetric source / sink term



DHI Software

DHI WATER & ENVIRONMENT

MIKE SHE UZ - Flow Theory

Darcy Law applied to vertical flow

$$q = K(\Theta)\frac{\partial h}{\partial z}$$

$$h = z + \psi$$

h : Hydraulic head

z : Gravitational head, elevation

ψ : Pressure head, tension < 0

Continuity Equation

$$\frac{\partial \theta}{\partial t} = -\frac{\partial q}{\partial z} - S(z)$$

Darcy + Continuity

>> Richards Equation

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial z}\left(K(\theta)\frac{\partial \psi(\theta)}{\partial z}\right) + \frac{\partial K(\theta)}{\partial z} - S(z)$$

S : Root extraction

Simple UZ solution (gravitational flow)

$$h = z, \quad \psi = 0$$

$$\frac{\partial h}{\partial z} = 1$$

For Richards Equation, two physical relations needed

- Water-retention - $\psi(\theta)$
- Hydraulic conductivity - $K(\theta)$

Must be solved numerically

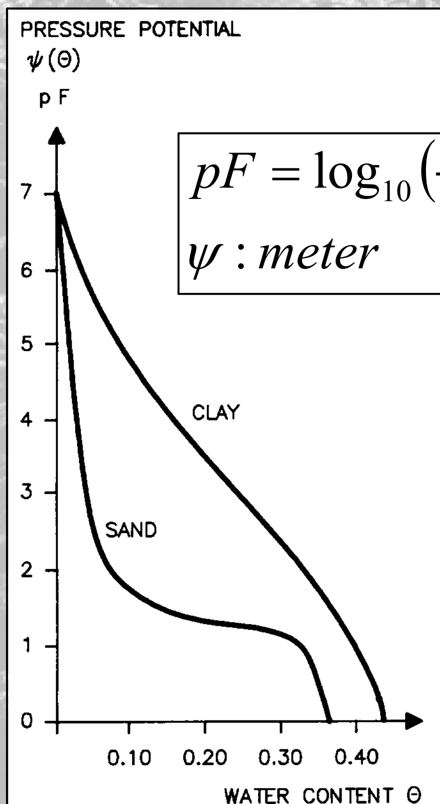
For Gravity Flow only requires

- Hydraulic conductivity - $K(\theta)$

Can be solved directly

MIKE SHE UZ - Soil Physical Properties

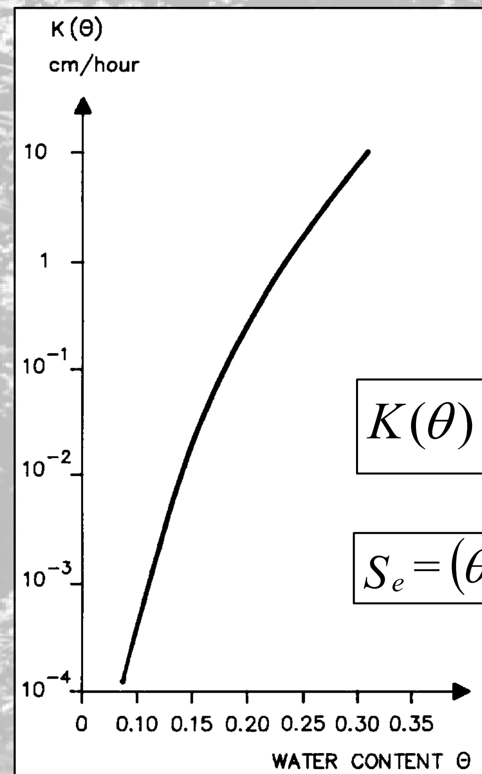
Water Retention Curve



$$pF = \log_{10}(-100\psi)$$

$$\psi : meter$$

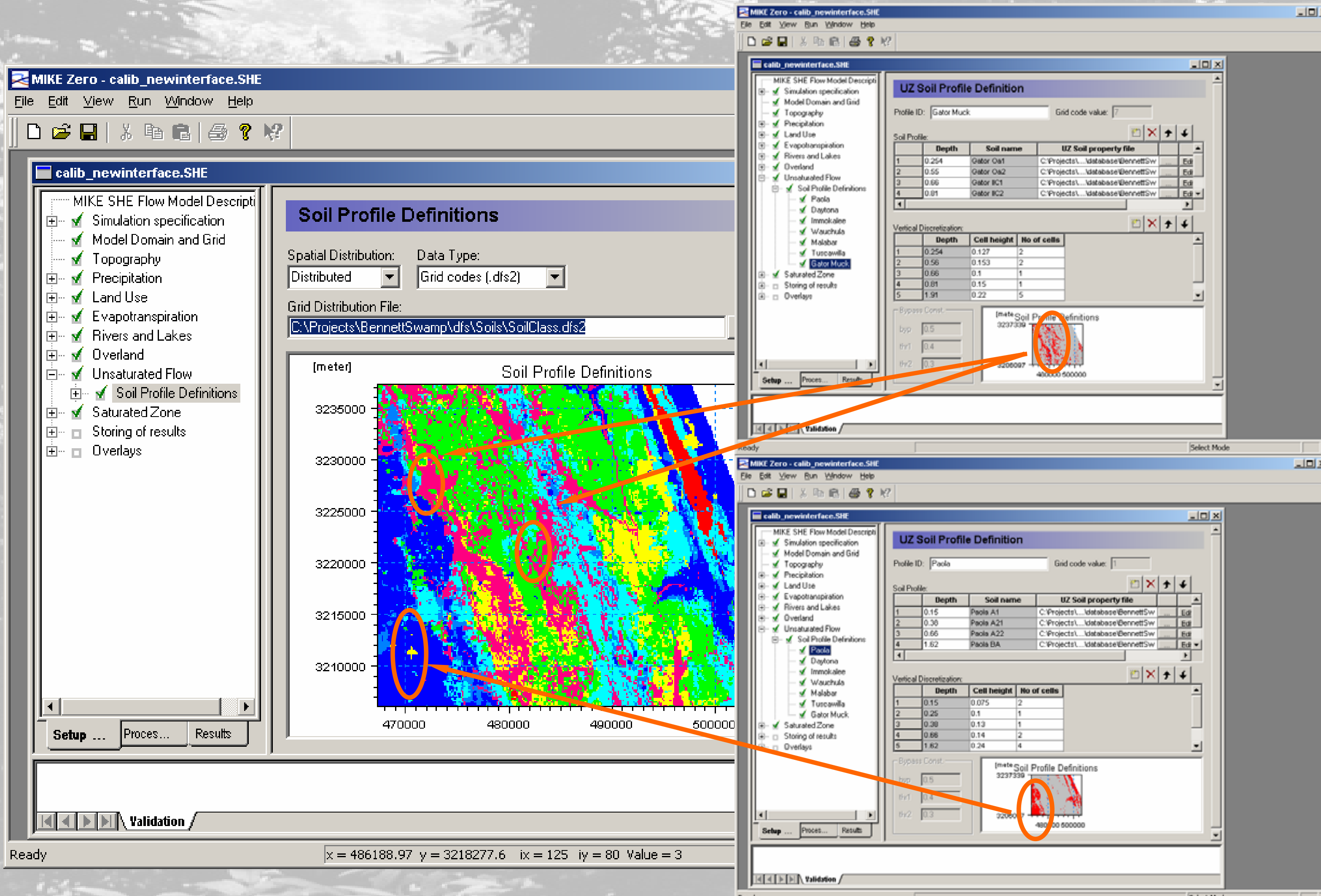
K(θ) Function (Averjanov)



$$K(\theta) = K_{sat} S_e^n$$

$$S_e = (\theta - \theta_r)/(\theta_s - \theta_r)$$

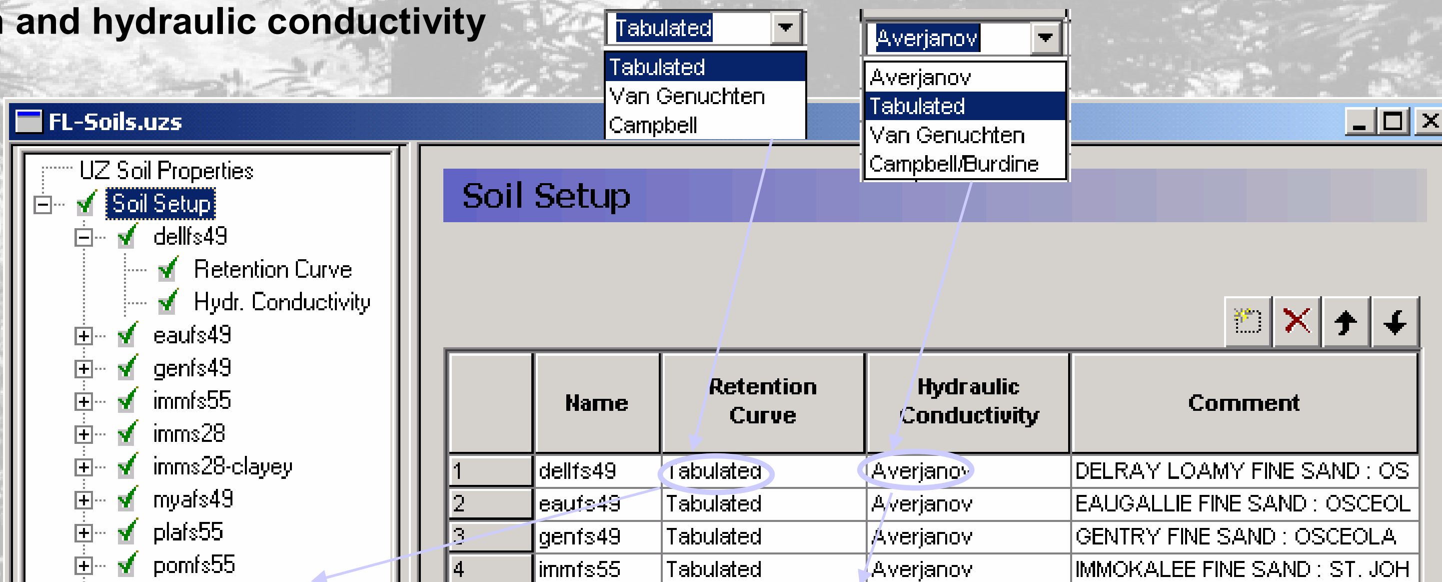
MIKE SHE UZ - Profile distribution

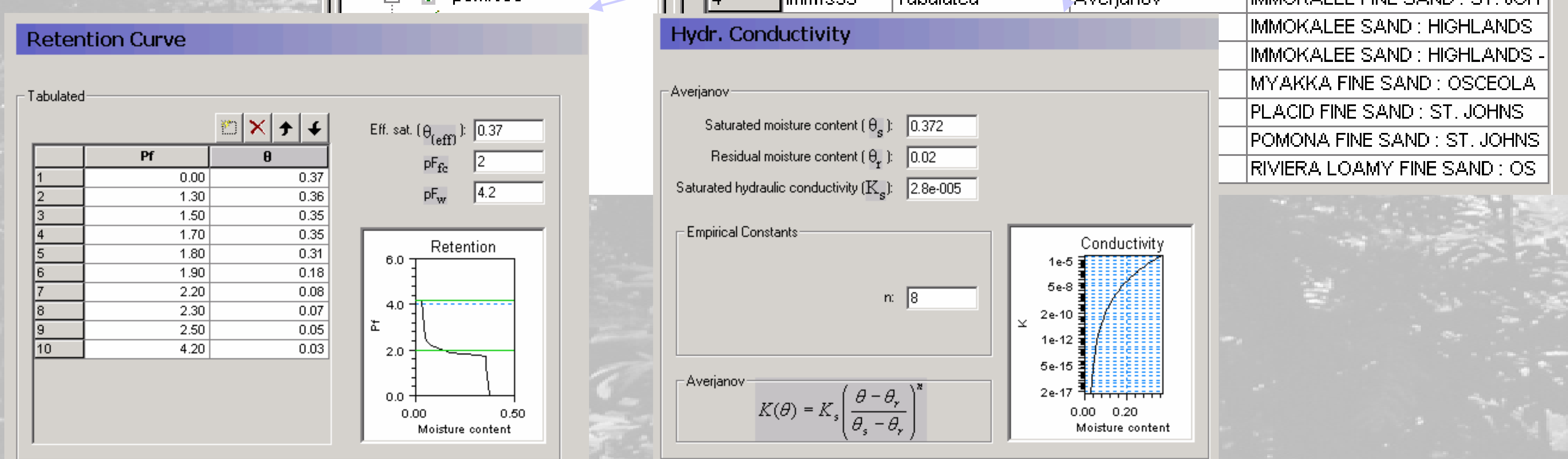


MIKE SHE UZ – soil property models

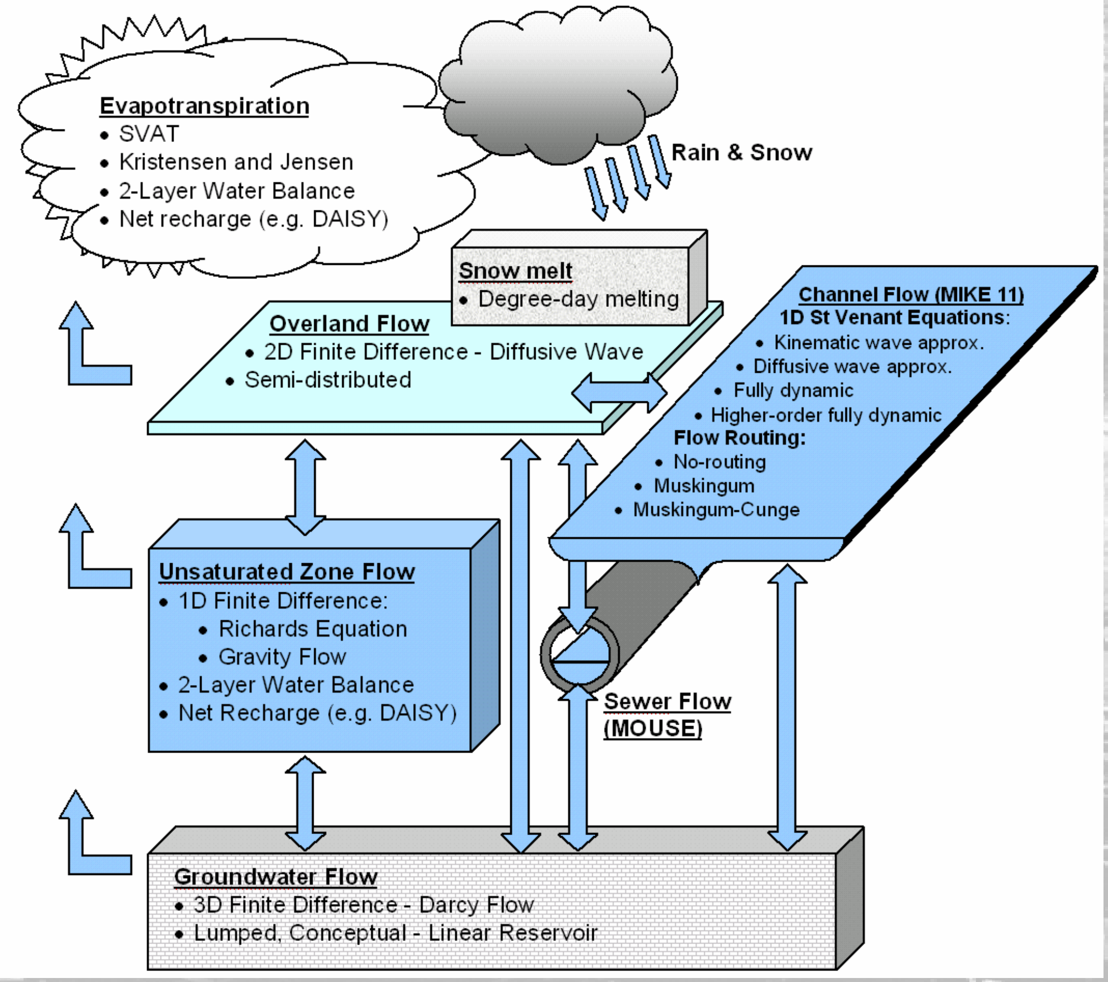
Various retention and hydraulic conductivity models allowed

Different models can be used for different soil types in the same UZ soil database, if appropriate.





MIKE SHE Overland Flow Component



Overland Flow Input Data

Topography

Controls direction of flow

Mannings M (or n)

Uniform or distributed

Detention Storage

Treshold for overland flow

Value reflects local storage (uniform or distributed)

Initial/boundary conditions Water depth

Initial condition (water level)

Water level on the model boundary

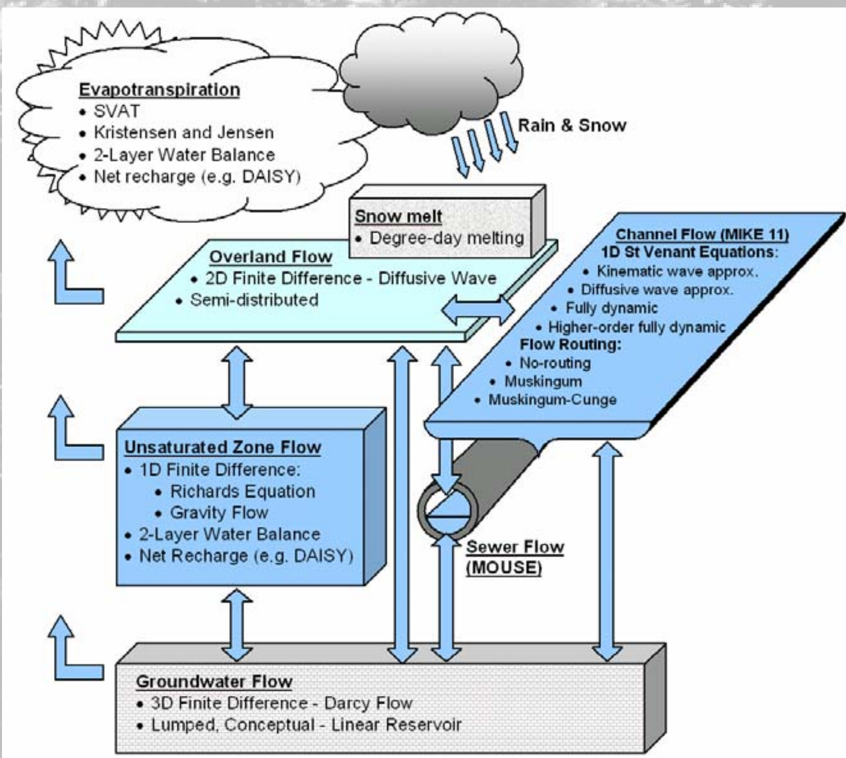
Lumped Overland Flow

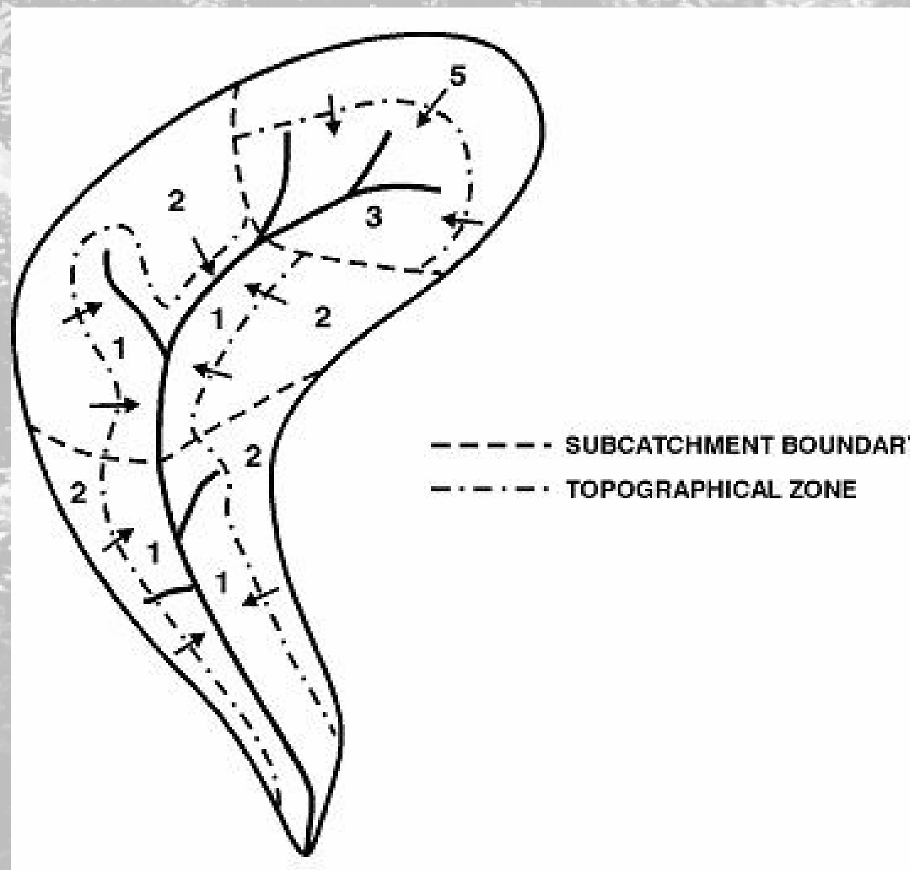
Subcatchments + Overland flow zones

Flow from higher to lower OL zone within a subcatchment area

e.g. Upland to floodplain within each subcatchment

Calculated using Manning equation with a conceptual flow length





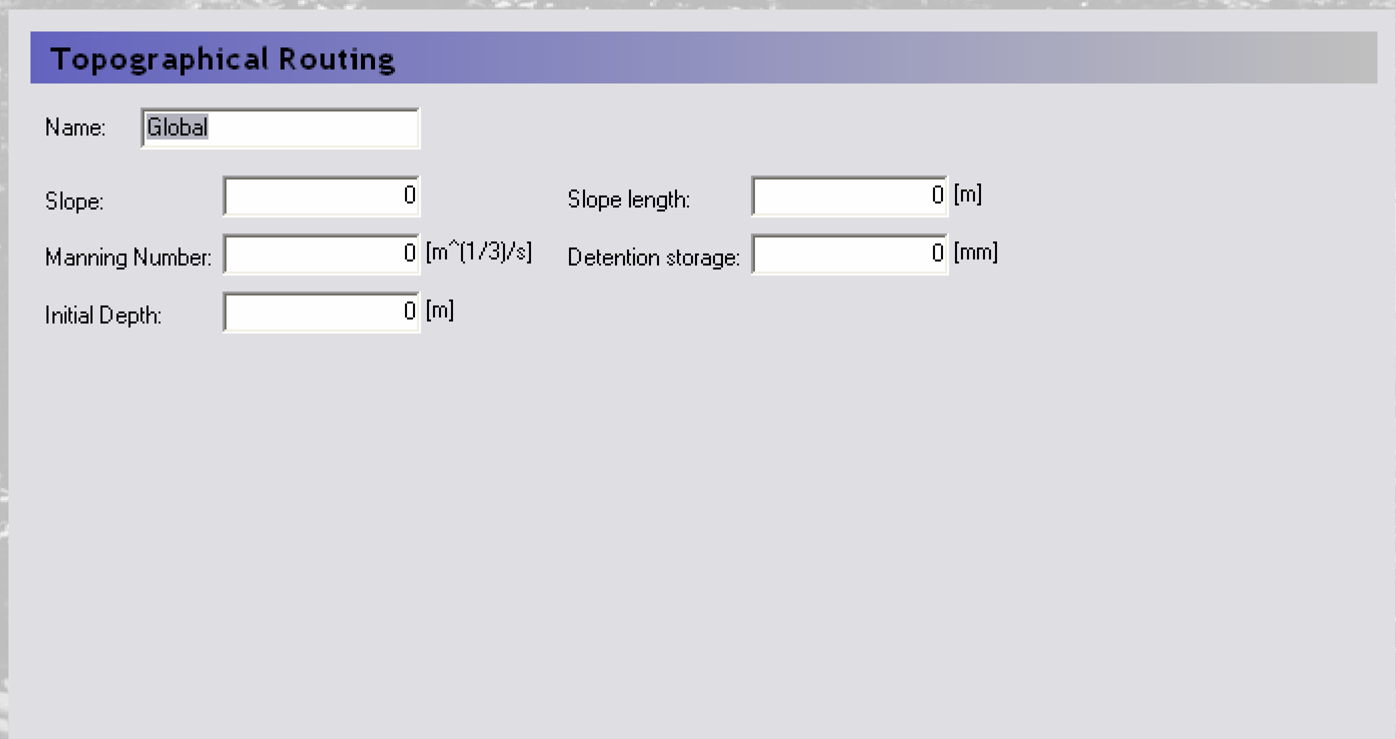
Input Data for Simple Overland Flow

Subcatchments + Overland flow zones (topographic routing zones)

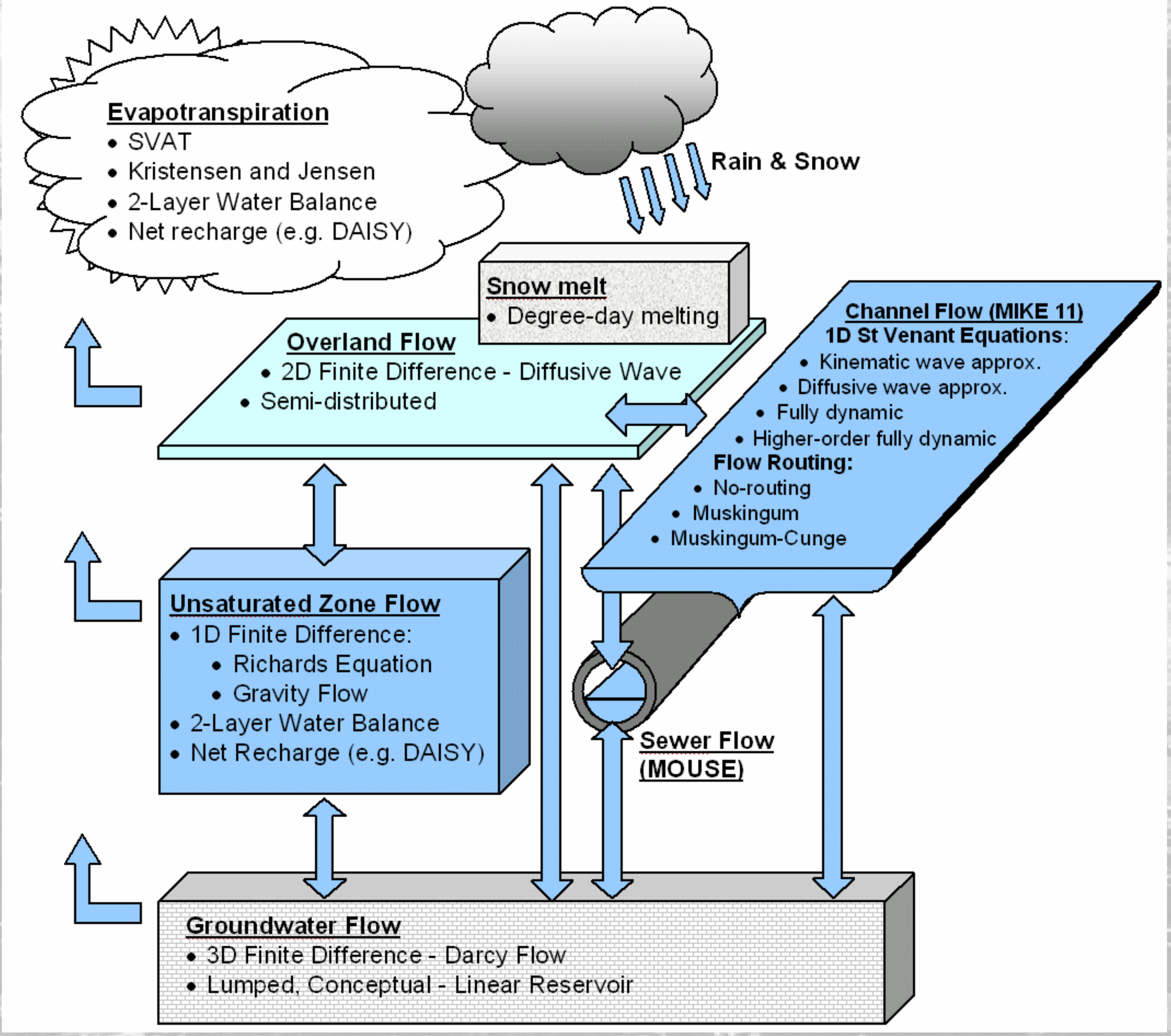
Slope - average slope in the zone

Slope length - average distance to a drainage feature

Manning M, Initial Depth, Detention Storage - same as FD



MIKE11 Channel flow

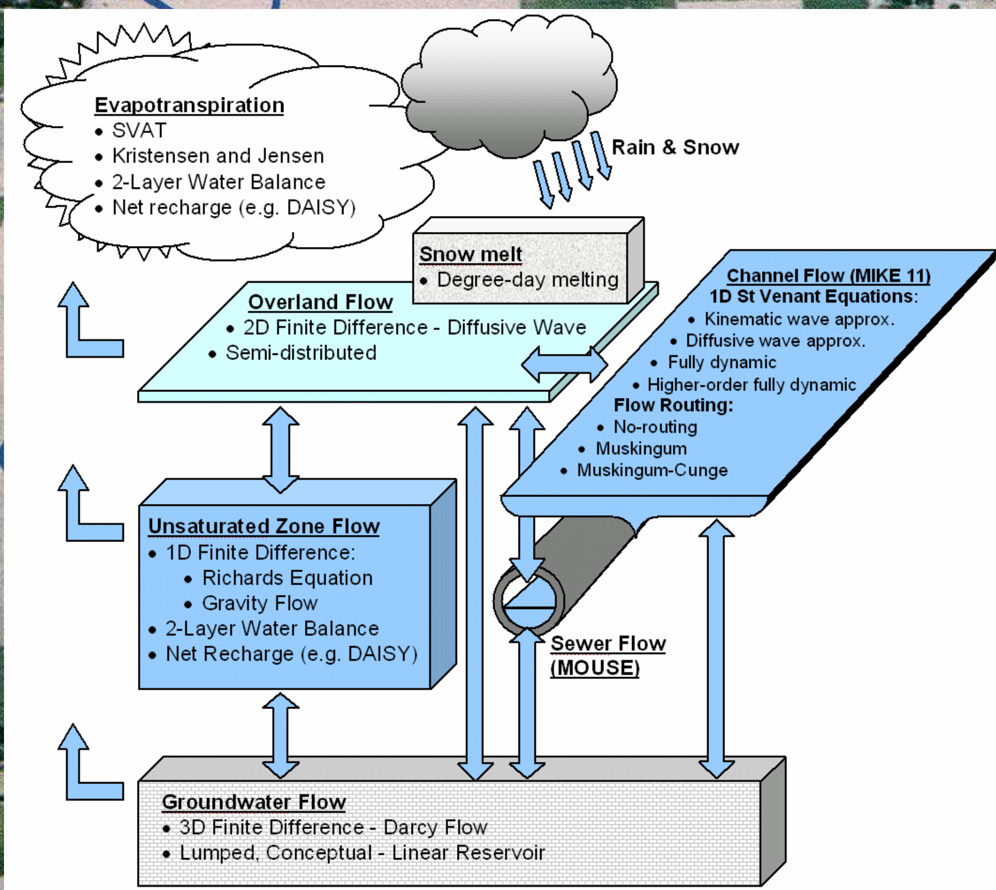


Rainfall-Runoff

Hydrodynamic

Flood Forecasting

ent Transport

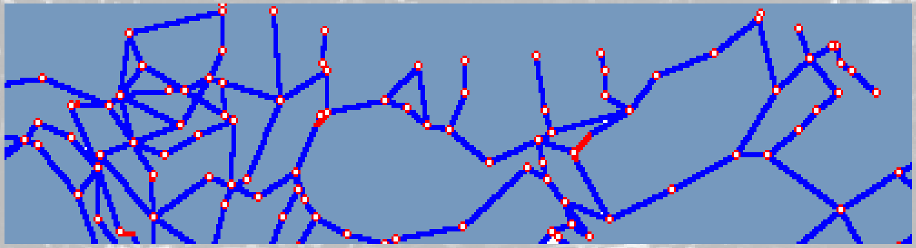


MIKE 11

d postprocessor

Hydrodynamic

- Looped network (1D+)
- Hydraulic Structures
  - Weirs
  - Culverts
  - Bridges
  - Regulation
  - Gates
  - Pumping
  - Control Structures
  - Dambreak Failures



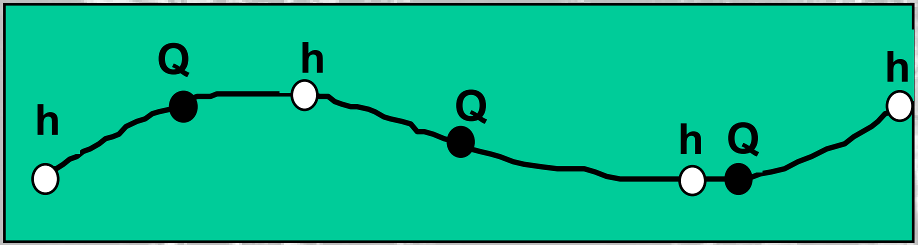
Hydrodynamics

Saint Venant Equations

$$\frac{\delta Q}{\delta x} + b\frac{\delta h}{\delta t} = 0, \qquad \frac{\delta Q}{\delta t} + \frac{\delta\left(\alpha \frac{Q^2}{A}\right)}{\delta x} + gA\frac{\delta h}{\delta x} = 0$$

6 Point Abbott-Ionescu FD Scheme

dynamic/diffusive/kinematic



Muskingum routing

Wave Approximations

$$\frac{\Delta M}{\Delta t} = \frac{\Delta (M \cdot U)}{\Delta x} + \frac{\Delta P}{\Delta x} - \frac{F_f}{\Delta x} + \frac{F_g}{\Delta x}$$

Momentum	Momentum Flux	Pressure	Friction	Gravity

fully dynamic wave

diffusive wave

kinematic wave

Kinematic wave applicable in steep rivers/streams with no backwater or tidal effects

Diffusive wave applicable in rivers/stream with relatively steady backwater effects or slowly propagating flood waves

Hydrograph Routing

Muskingum routing

Routing is a lumped hydrograph transformation calculation. Typically a routing element represents a reach of a river, a reservoir or a hydraulic structure. Routing does not require X-section data.

$$Q_{i+1}^{j+1} = C_1 Q_i^{j+1} + C_2 Q_i^{j} + C_3 Q_{i+1}^{j} + C_4$$

C1, C2, C3, C4 : functions of K, x and dT (e.g $C_1 = \dfrac{\Delta t - 2Kx}{2K(1-x)+\Delta t}$)

Muskingum Cunge

$$K = \frac{\Delta x}{c_k}$$

$$x = \frac{1}{2}\left(1 - \frac{Q}{Bc_k S_0 \Delta x}\right)$$

$$c_k = \frac{dQ}{dA} = \frac{\partial Q}{\partial x} / \frac{\partial A}{\partial x} + \frac{\partial Q}{\partial t} / \frac{\partial A}{\partial t}$$

S0 is slope, B is X-sec width and A is X-sec area

- Or no routing (i.e. downstream flow accumulation only)

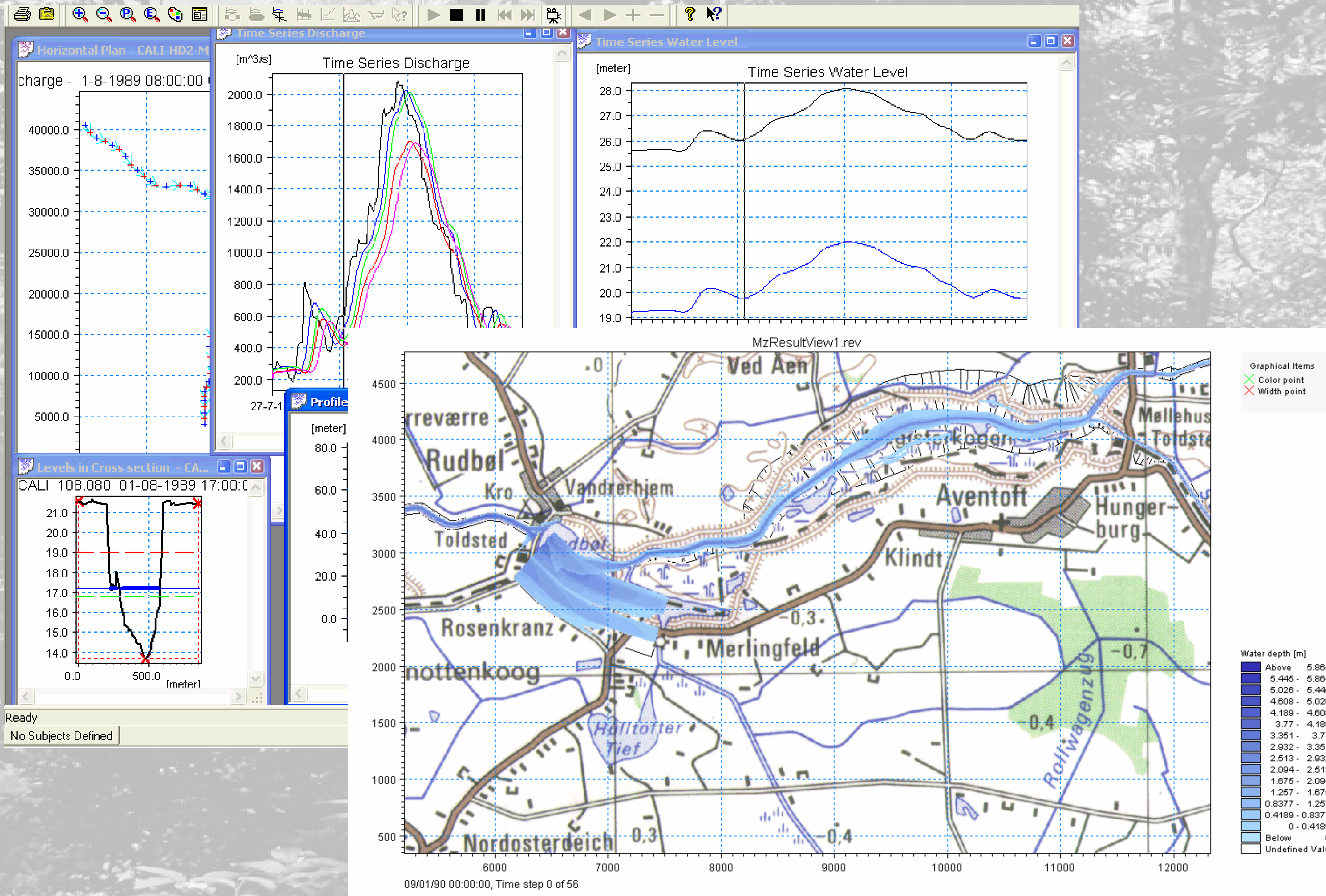
Routing

Water level in Muskingum
- Manning formula
- Q-H relation

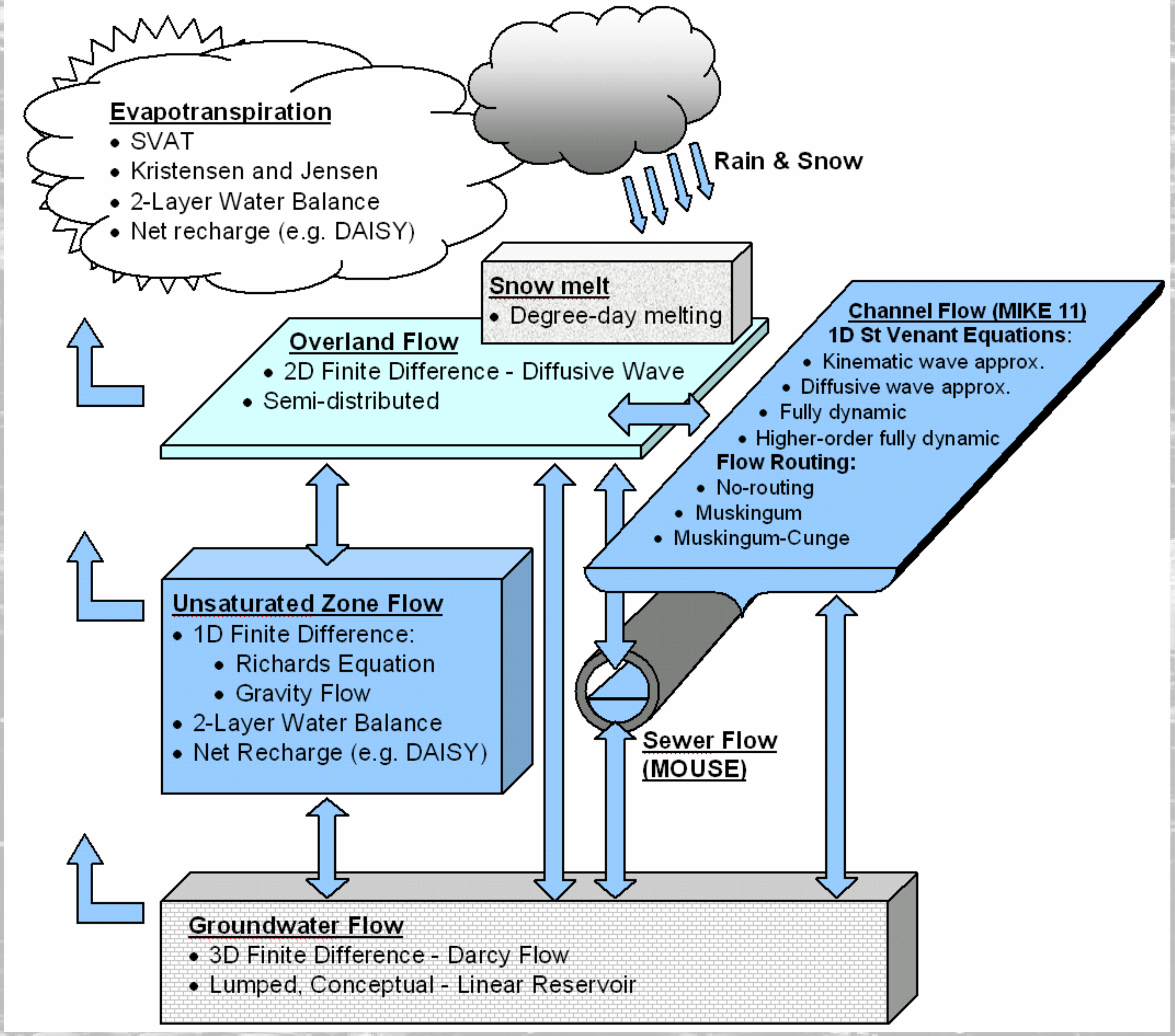
Benefits and drawbacks of routing compared to Saint Venant wave approximations :
- more stable
- Reduction of simulation run time
- Routing is lumped and potentially less accurate

Combination of branch types - the most critical point controls time step of the entire simulation - nothing gained by adding a few routing branches – except perhaps stability also for extremely steep rivers

MIKE11 ouputs



MIKE SHE SZ

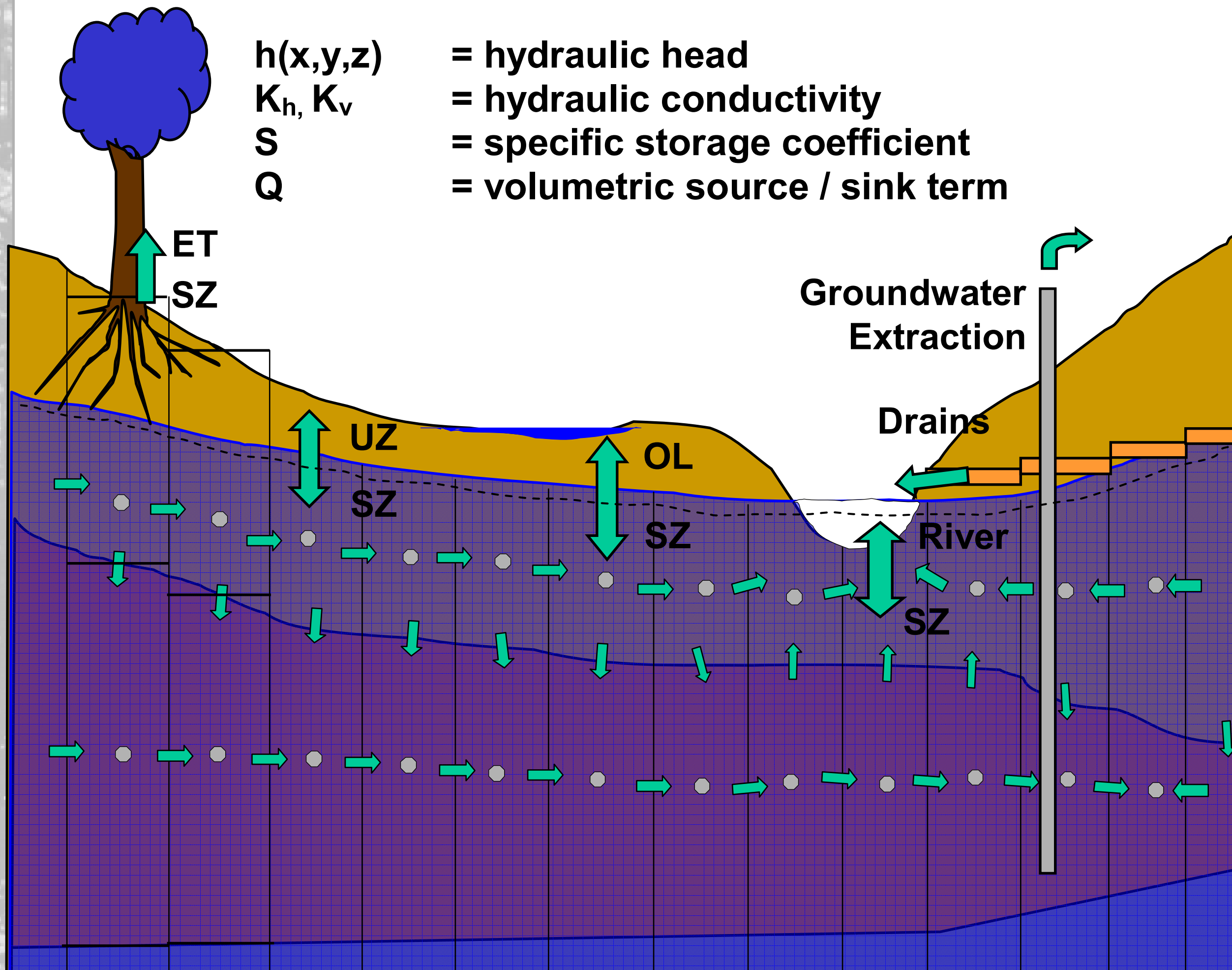

Evapotranspiration
• SVAT
• Kristensen and Jensen
• 2-Layer Water Balance
• Net recharge (e.g. DAISY)
Rain & Snow
Snow melt
• Degree-day melting
Overland Flow
• 2D Finite Difference - Diffusive Wave
• Semi-distributed
Channel Flow (MIKE 11)
1D St Venant Equations:
• Kinematic wave approx.
• Diffusive wave approx.
• Fully dynamic
• Higher-order fully dynamic
Flow Routing:
• No-routing
• Muskingum
• Muskingum-Cunge
Unsaturated Zone Flow
• 1D Finite Difference:
• Richards Equation
• Gravity Flow
• 2-Layer Water Balance
• Net Recharge (e.g. DAISY)
Sewer Flow
(MOUSE)
Groundwater Flow
• 3D Finite Difference - Darcy Flow
• Lumped, Conceptual - Linear Reservoir

MIKE SHE Saturated Flow

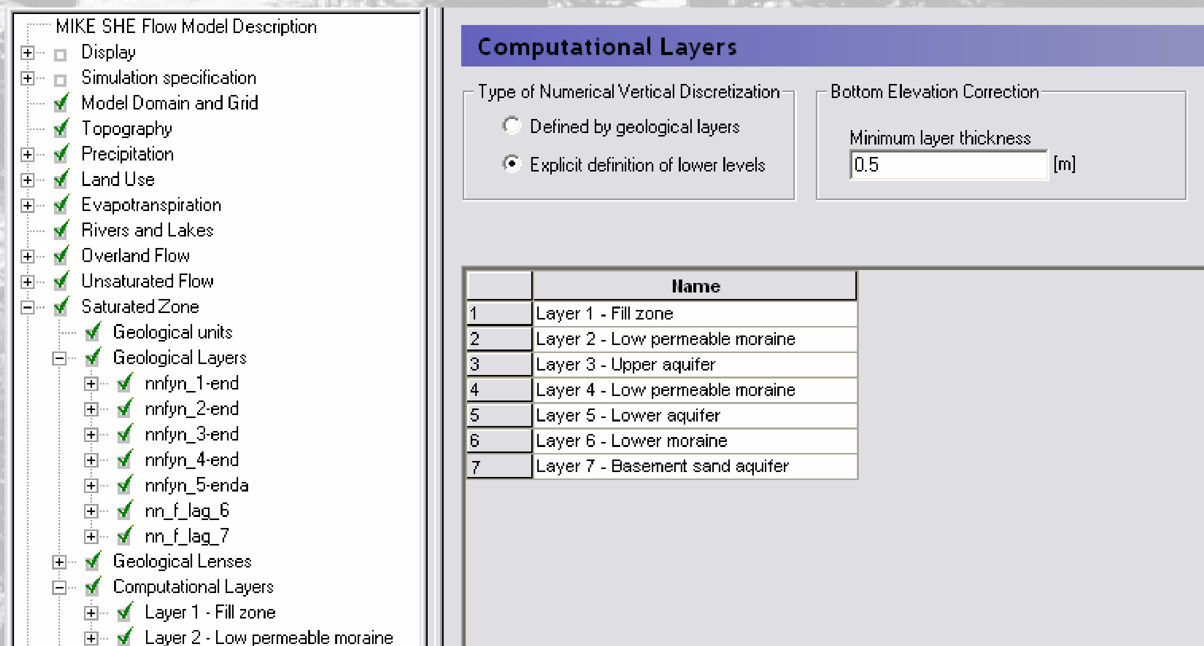
Three dimensional flow in porous media

$$\frac{\partial}{\partial x}\left(K_h \frac{\partial h}{\partial x}\right) + \frac{\partial}{\partial y}\left(K_h \frac{\partial h}{\partial y}\right) + \frac{\partial}{\partial z}\left(K_v \frac{\partial h}{\partial z}\right) - Q = S\frac{\partial h}{\partial t}$$

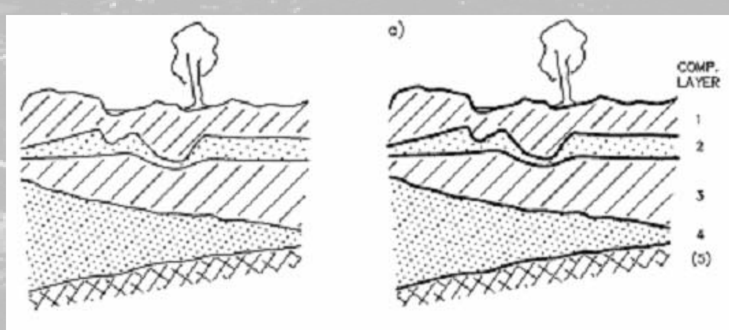
h(x,y,z)	**= hydraulic head**
K_{h}, K_{v}	**= hydraulic conductivity**
S	**= specific storage coefficient**
Q	**= volumetric source / sink term**



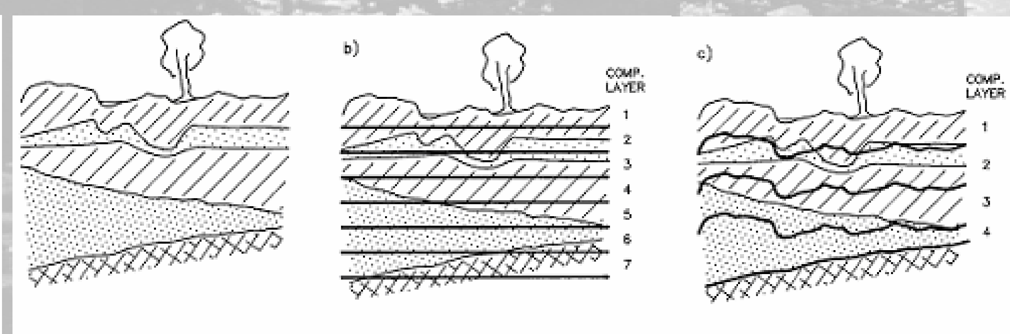
Vertical Discretization



Defined by Geological Layers



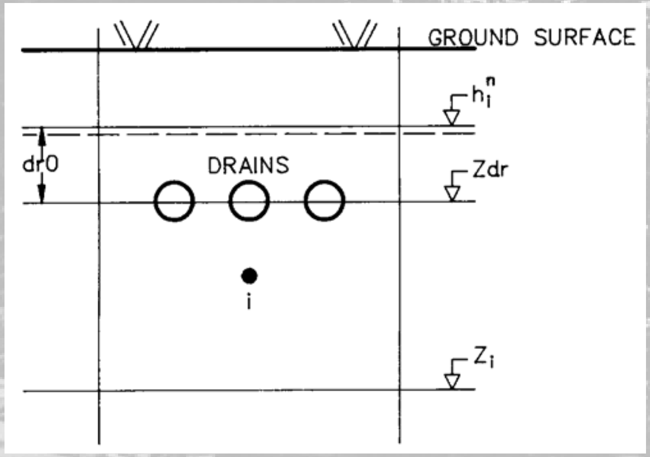
- Or whatever layer geometry you want



Saturated Zone Drainage

- **Is a special SZ boundary condition for**
  - **flow through installed drains in the soil**
  - **flow to natural drainage networks (creeks, ditches not in the HD model)**

- **Drain flow occurs when the water table is above the Drain Level**
- **Drainage is conceptually modelled as one `big` drain within a grid square.**
- **The outflow depends on the height of the water table above the drain and a specified time constant**
- **Drainage is computed as a linear reservoir.**
- **The time constant characterises the relative efficiency of the drains (e.g drain density, drain clogging, age, etc).**

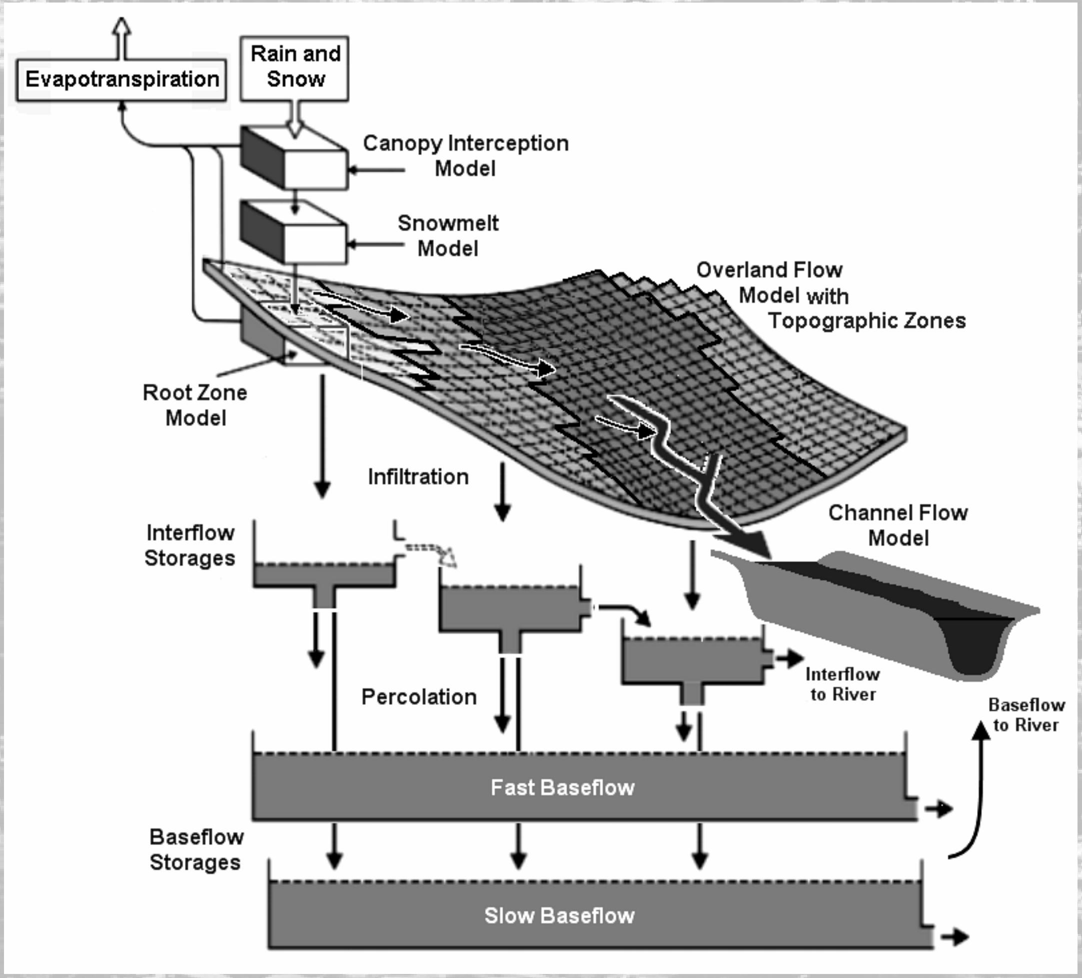


U = dr0 * Cdr [m/s]

Qdrain = A * U [m3/s]

MIKE SHE

Simple Linear-reservoir groundwater



- easy to build and calibrate
- Computationally almost free
- One hydrograph for each reservoir

- Does not give you distributed groundwater level – no good for groundwater related flooding issues.

Surface water – groundwater interactions

Exchange between Surface Water and Aquifer

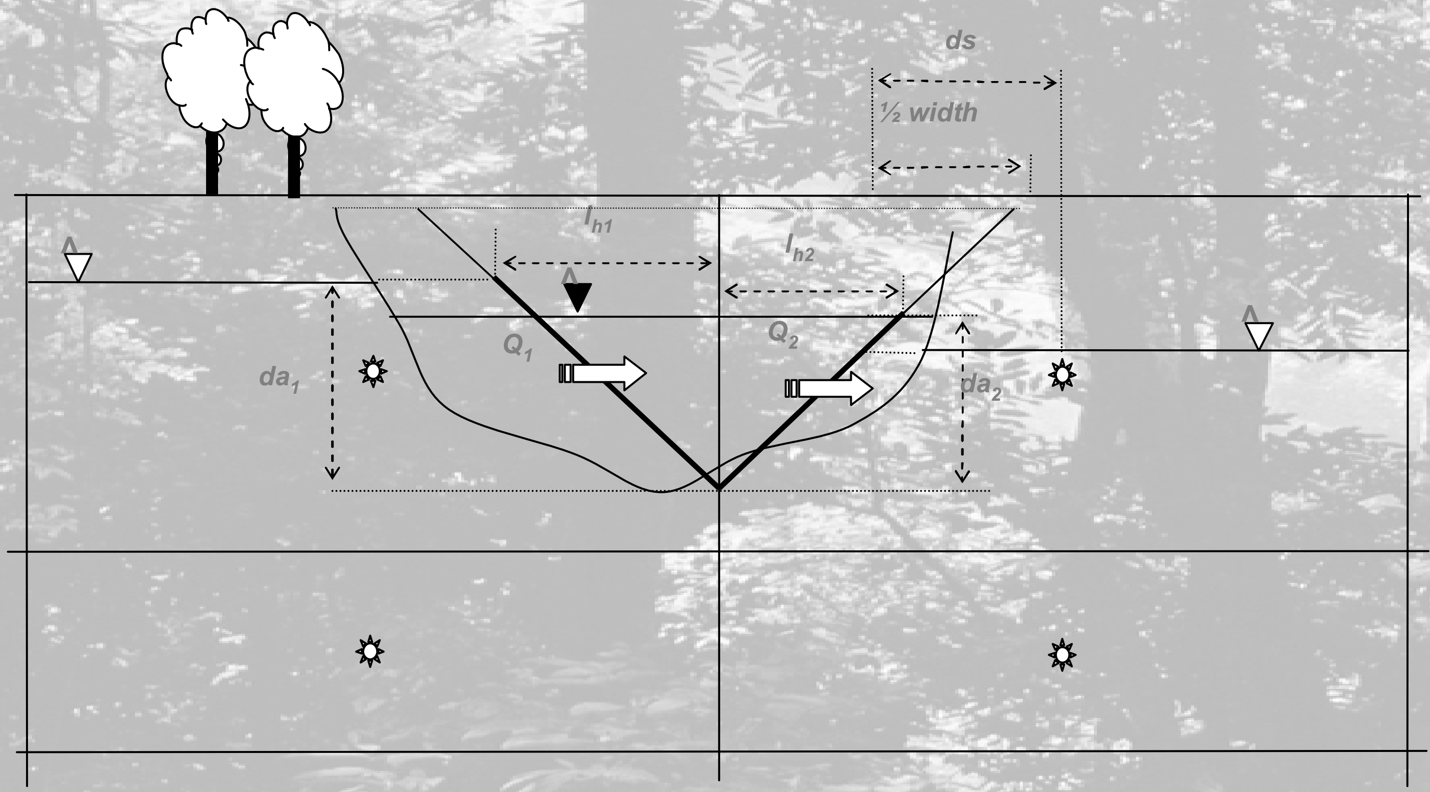
The MIKE SHE/MIKE 11 modeling system considers two principally different surface water/aquifer exchange options:

- River-aquifer exchange where the river is considered a line source/sink located between two adjacent model grids
- An area-inundation flood mapping (wide rivers, floodplains, lakes)


DHI Software
DHI
WATER & ENVIRONMENT

MIKE SHE – MIKE 11 Coupling

River Aquifer Exchange



MIKE SHE – MIKE 11 Coupling

River Conductance

The conductance is calculated in different ways depending on the option specified in the user interface.

Full contact flow resistance

$$C_{i,sz-river} = C_i / ds \cdot da_i \cdot dx$$

Reduced contact - flow resistance in river lining and SZ

$$C_{i,sz-river} = \frac{1}{\dfrac{ds}{C_i \cdot da_i \cdot dx} + \dfrac{1}{C_{i,river} \cdot w_i \cdot dx}}$$

Reduced contact - flow resistance in river lining

$$C_{i,sz-river} = C_{i,river} \cdot w_i \cdot dx$$

$C_{i,sz\text{-}river}$	Conductance between layer *i* and river
C_i	hydraulic conductivity in saturated zone
$C_{i,river}$	leakage coefficient of river lining
da_i	saturated layer thickness
dx	SZ grid size
ds	Average flow length - distance from center of grid to half half-width of riverbank.
w_i	assumed wetted perimeter in grid *i* ($l_{i,v}+l_{i,h}$)

MIKE SHE – MIKE 11 Coupling

Head Difference

Head difference between the river and the saturated zone is calculated by

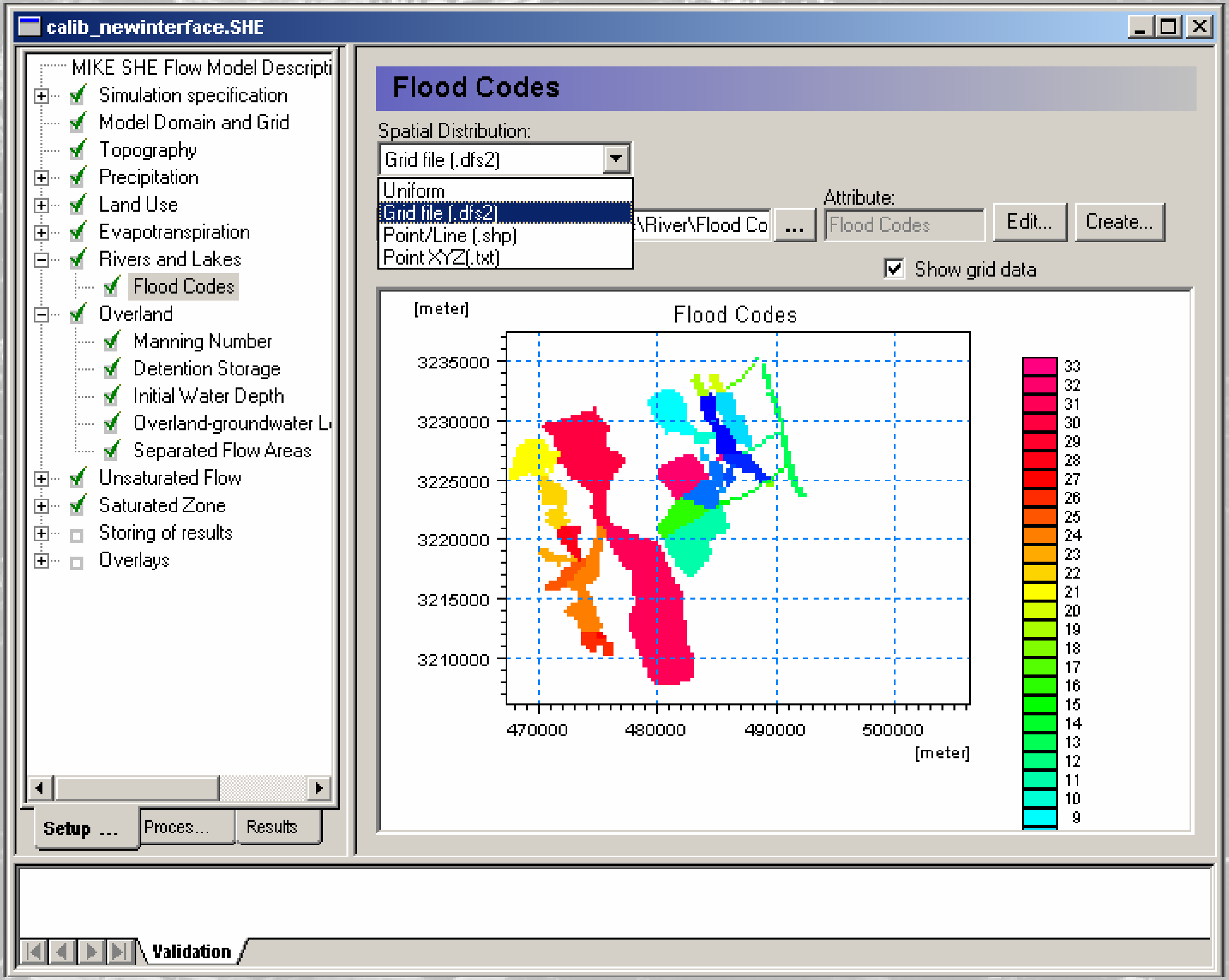
$$\Delta h = h_i - h_{riv}$$

If the ground water level drops below the river bed level the head difference is calculated as

$$\Delta h = z_{bot} - h_{riv}$$

MIKE SHE – MIKE 11 Coupling
Area-inundation

Define potentially Flooded Areas and associate them with river branches

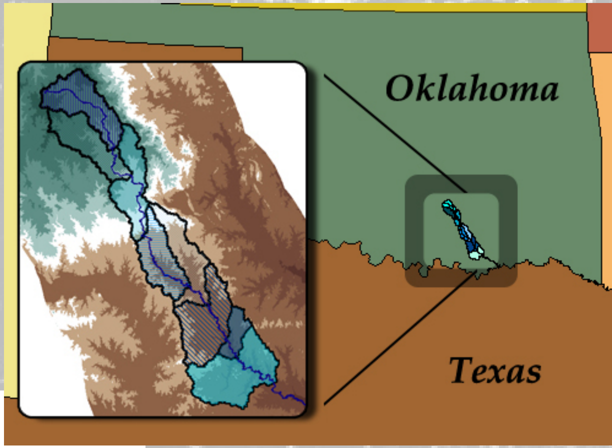


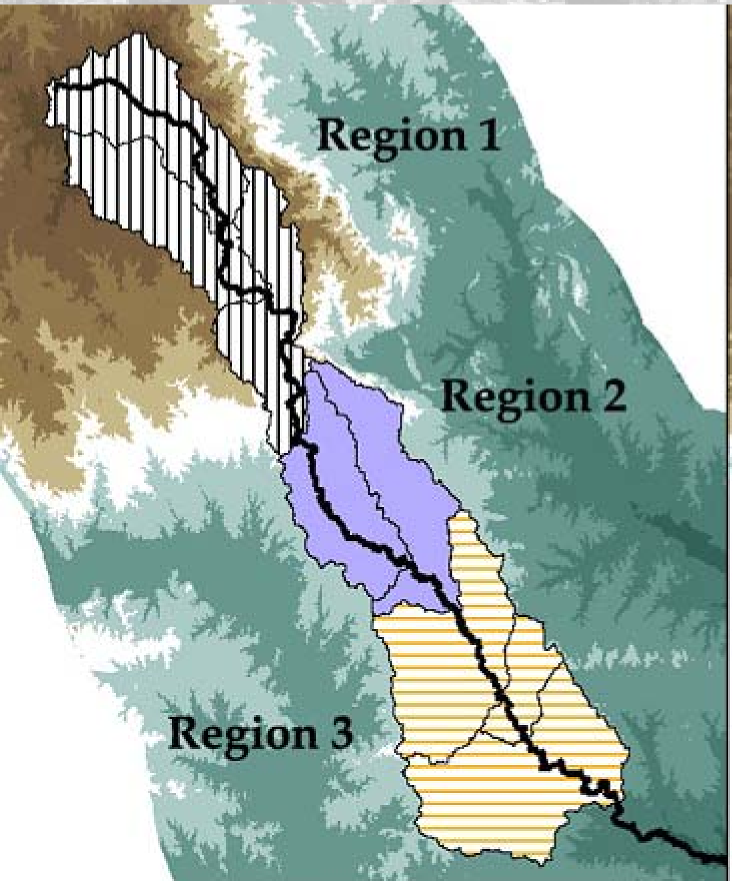
MIKE SHE

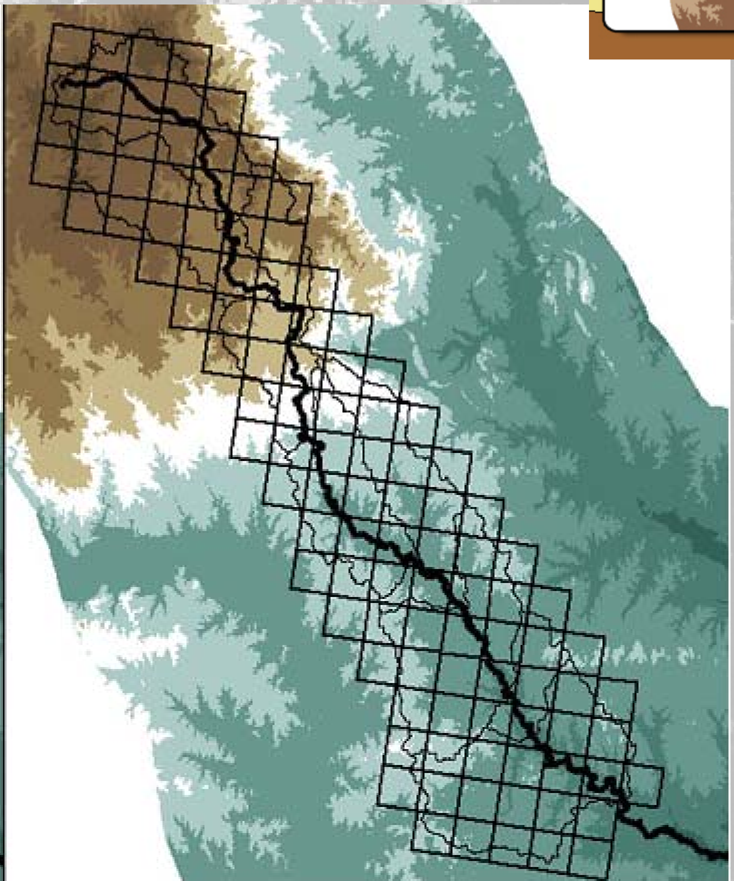
A few application examples

MIKE SHE has been used in hundreds of consulting and research projects around the world

Blue River Study Catchment







DMIP Project

Distributed Model Intercomparison Project (DMIP)

Organized by the US National Weather Service, Hydrology Laboratory

Primary objectives

To identify and help develop models and modelling systems that best utilise NEXRAD and other spatial data sets to improve RFC-scale river simulations

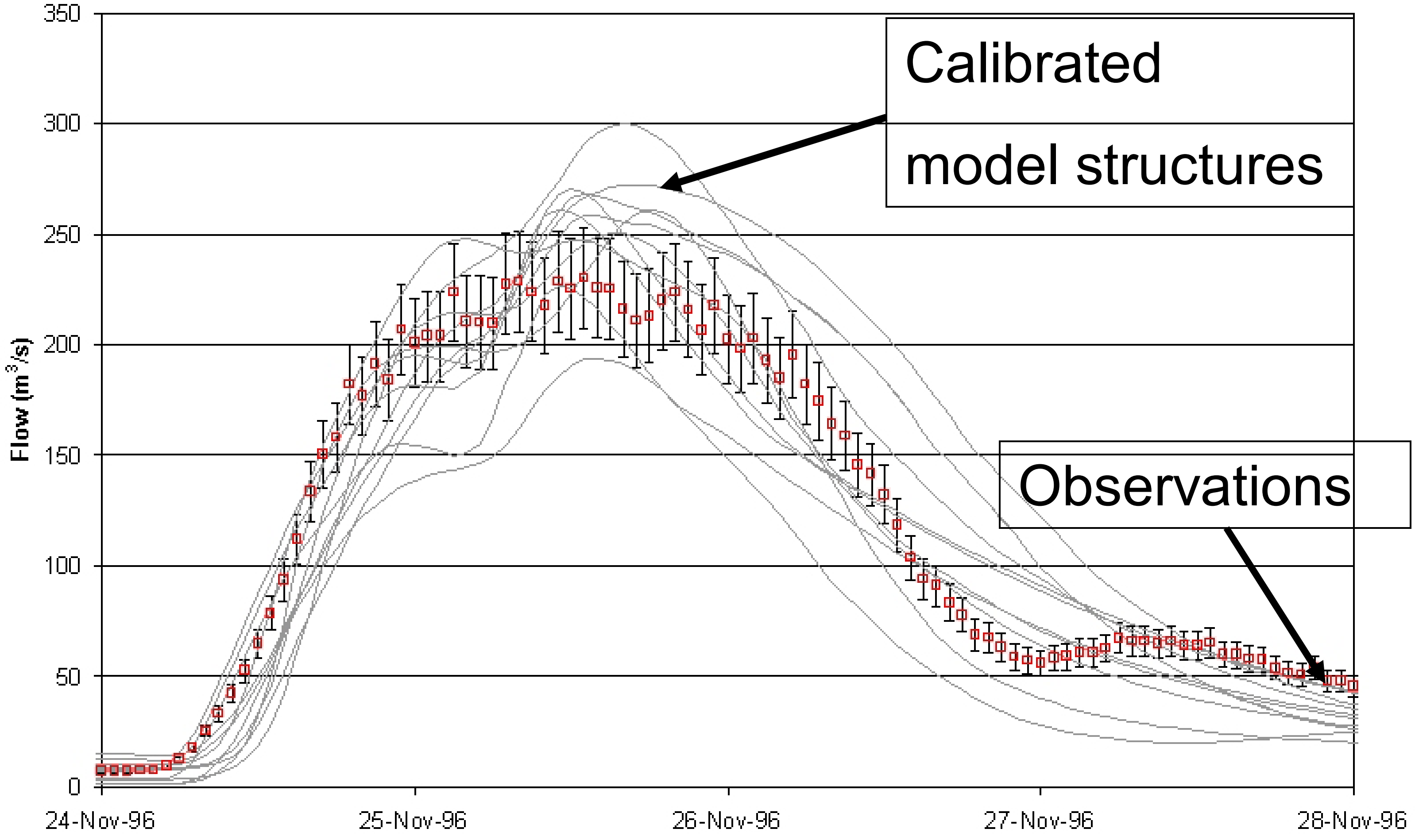
To help guide NWS/HL's distributed hydrologic modelling research, science, and applications.

Model structures

Table 1. Matrix summary of model structures used in this study

		Processes					Spatial Distributions		
ID	*Short Name*	*Routing Equation*	*Unsaturated Zone*	*Bypass*	*Drainage flow*	*Groundwater*	*Rainfall*	*Parameters*	*Elements*
s1	lumped	Lumped	Conceptual	no	no	conceptual	lumped	lumped	basin
s2	distributed routing	Fully dynamic	Conceptual	no	no	conceptual	sub-basin	lumped	sub-basin
s3	muskingum	Muskingum-cunge	Conceptual	no	no	conceptual	sub-basin	lumped	sub-basin
s4	distributed rainfall	Fully dynamic	Conceptual	no	no	conceptual	sub-basin	lumped	sub-basin
s5	3 regions	Fully dynamic	Conceptual	no	no	conceptual	sub-basin	3 regions	sub-basin
g1	*aggregated rainfall*	Fully dynamic	1D Gravity Drainage	no	yes	2D Darcy Flow	sub-basin	4km grid	grid
g2	*gridded rainfall*	Fully dynamic	1D Gravity Drainage	no	yes	2D Darcy Flow	4km grid	4km grid	grid
g3	*no drains*	Fully dynamic	1D Gravity Drainage	no	no	2D Darcy Flow	sub-basin	4km grid	grid
g4	*linear reservoir*	Fully dynamic	1D Gravity Drainage	no	yes	conceptual	sub-basin	4km grid/sub-basin	grid/sub-basin
g5	*bypass infiltration*	Fully dynamic	1D Gravity Drainage	yes	yes	conceptual	sub-basin	4km grid/sub-basin	grid/sub-basin

Blue River - Event 10



Journal of Hydrology paper

Okawanga Delta Management Plan (On-going)

Impact assessment of :

Surface and ground water abstraction from the Delta

Channel dredging

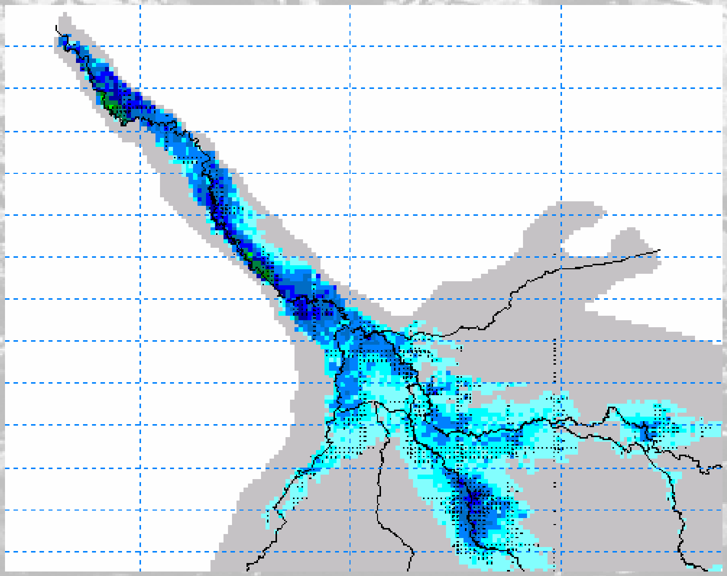
Cutting reeds

Upstream water resources developments

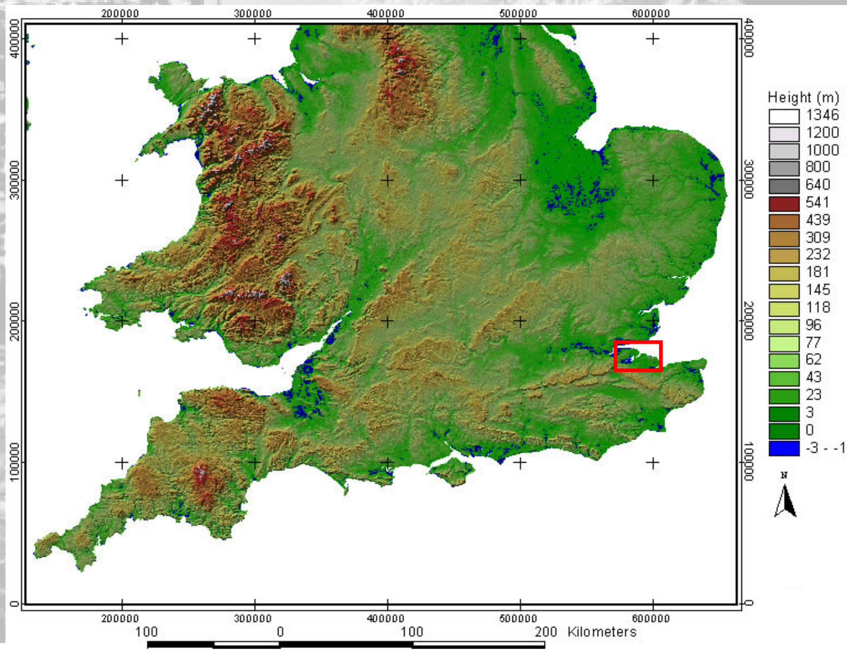
Climate changes

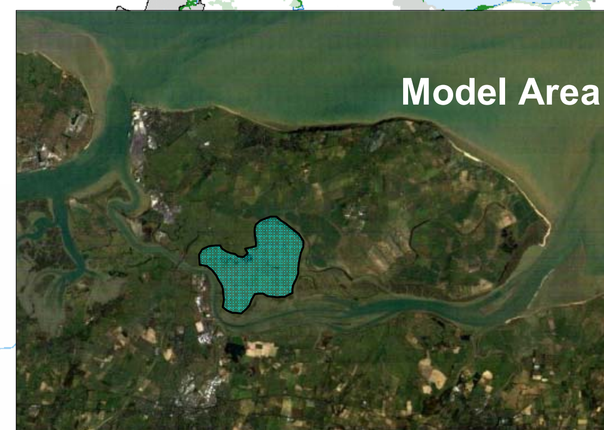
…

Development of an integrated hydrological model to support management decisions



The North Kent Marshes





1935

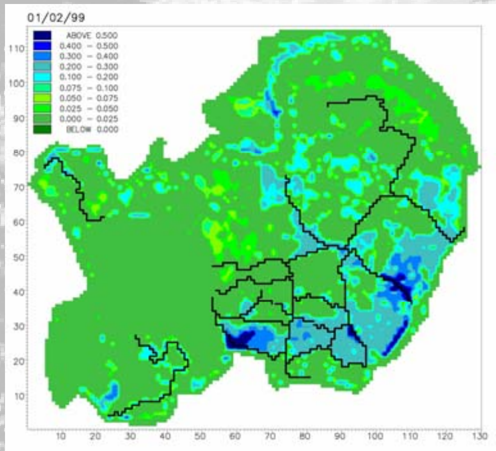
1968
16% loss

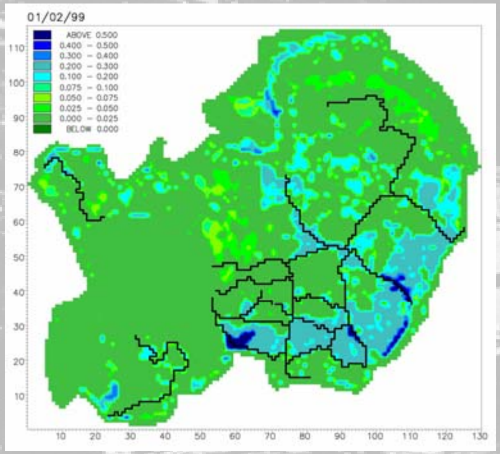
1982
48% loss

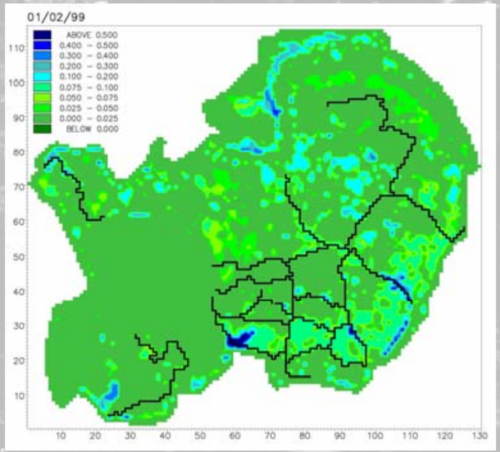
Wetland Research Unit, Department of Geography, University College London

Scenarios

To evaluate the impacts of water level manipulation on ditch water, groundwater and surface inundation







Journal of Hydrology paper

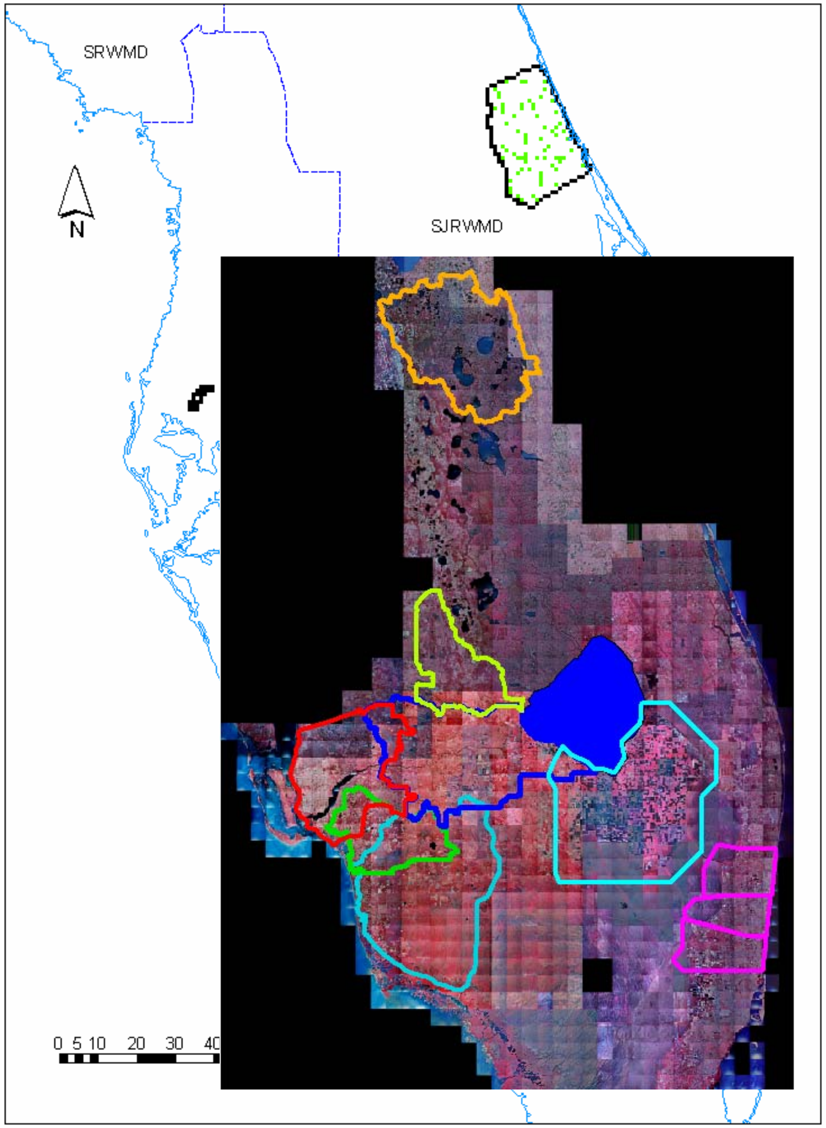
MIKE SHE High-Tech

Integrated Hydrological Modeling in Florida

SFWMD
- **ENR site**
- **Lake Toho / Alligator Lake**
- **Freshwater Caloosahatchee River Basin**
- **Tidal Caloosahatchee River Basin**
- **Estero-Imperial-Cocohatchee Basins**
- **Big Cypress Basin**
- **Broward County Model (CADA, NADA, SADA)**
- **Everglades Agricultural Area**
- **Fish Eating Creek**

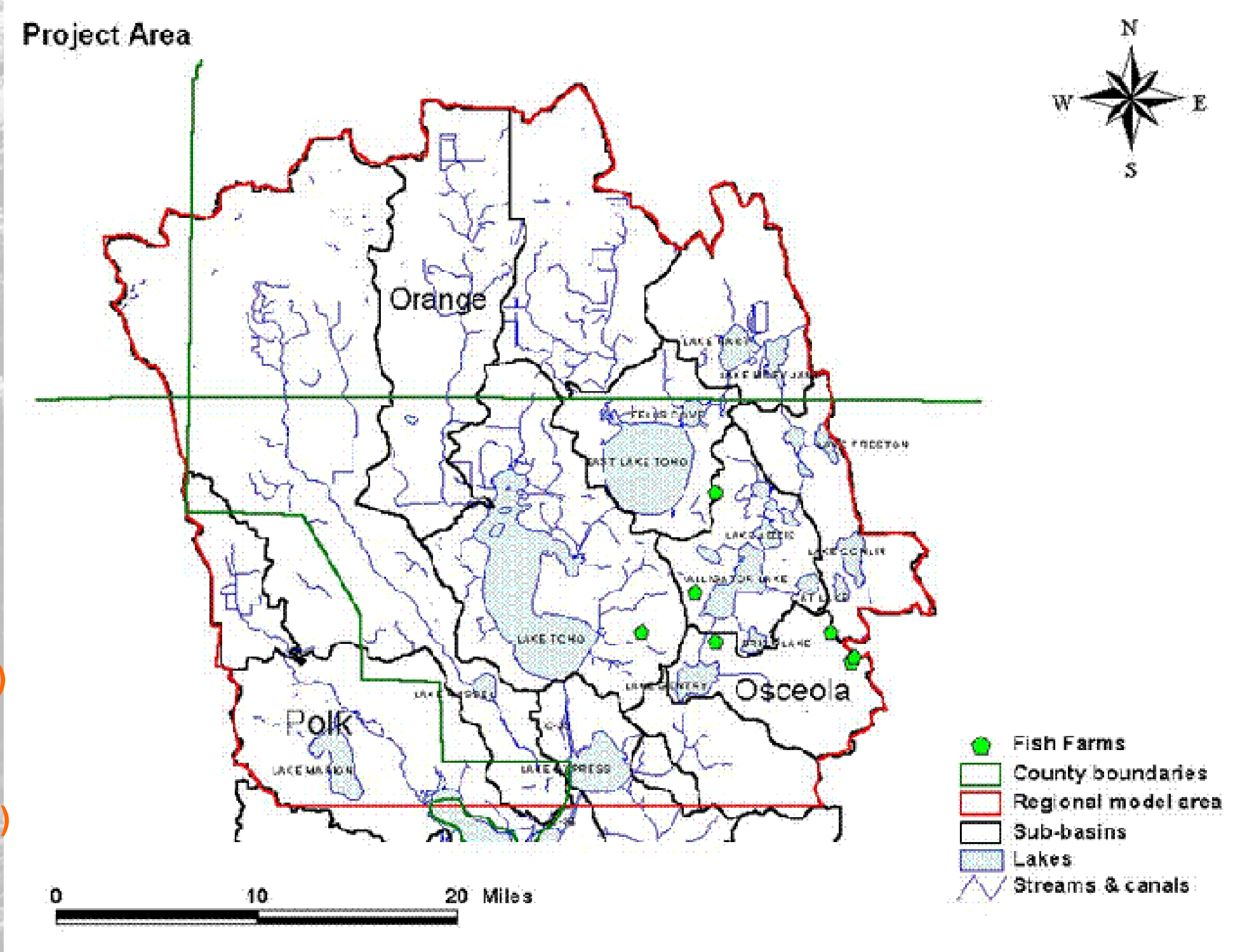
SJRWMD
- **Tiger Bay – Bennett Swamp (Phase 1 and 2)**

SWFWMD
- **Lake Armistead**
- **Horse Creek Basin / Peace river basin**



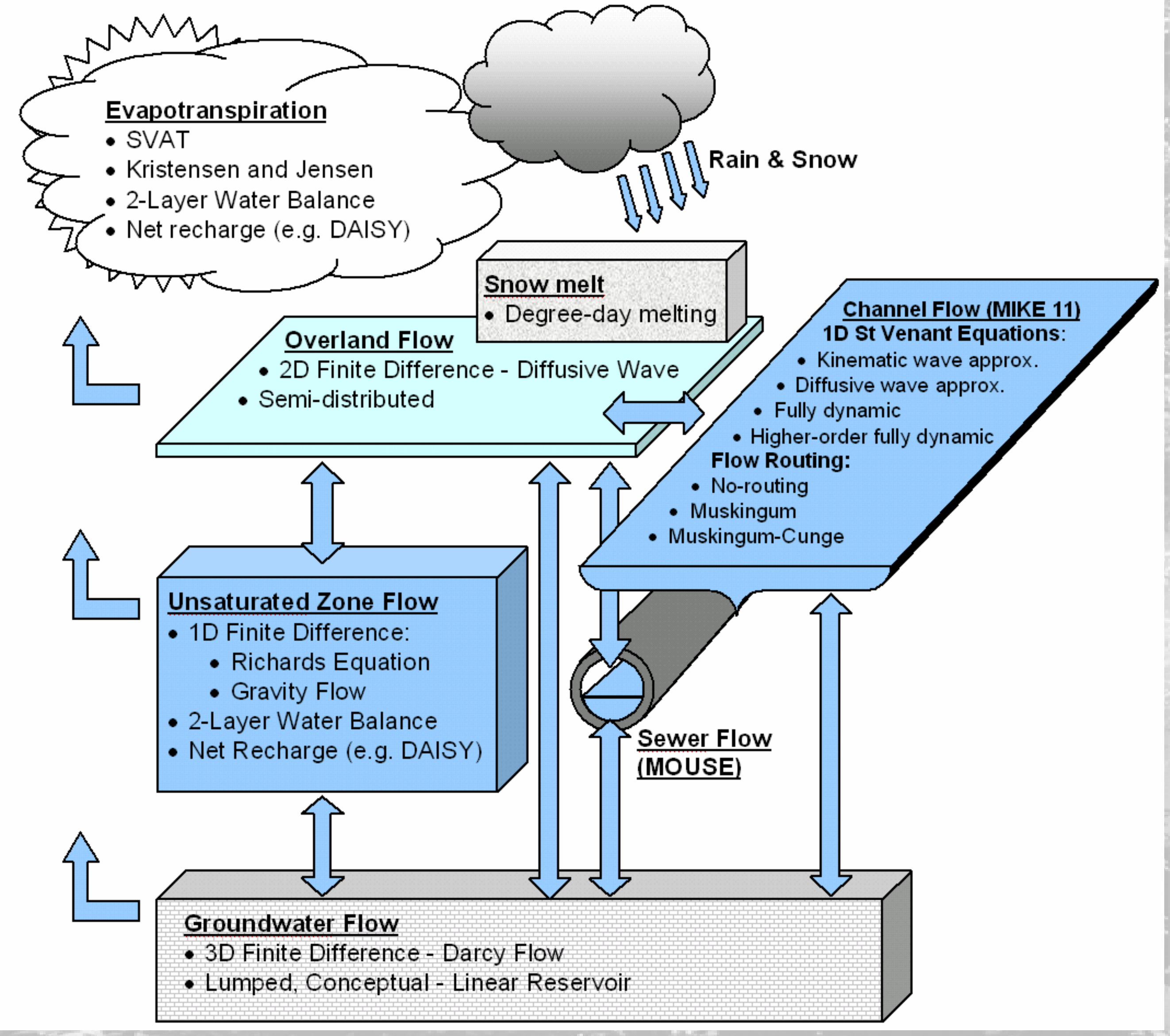
First MIKE SHE application in South Florida was in 1996 (ENR site)

Upper Kissimmee Model (Lk. Toho drawdown project) 2000-2001

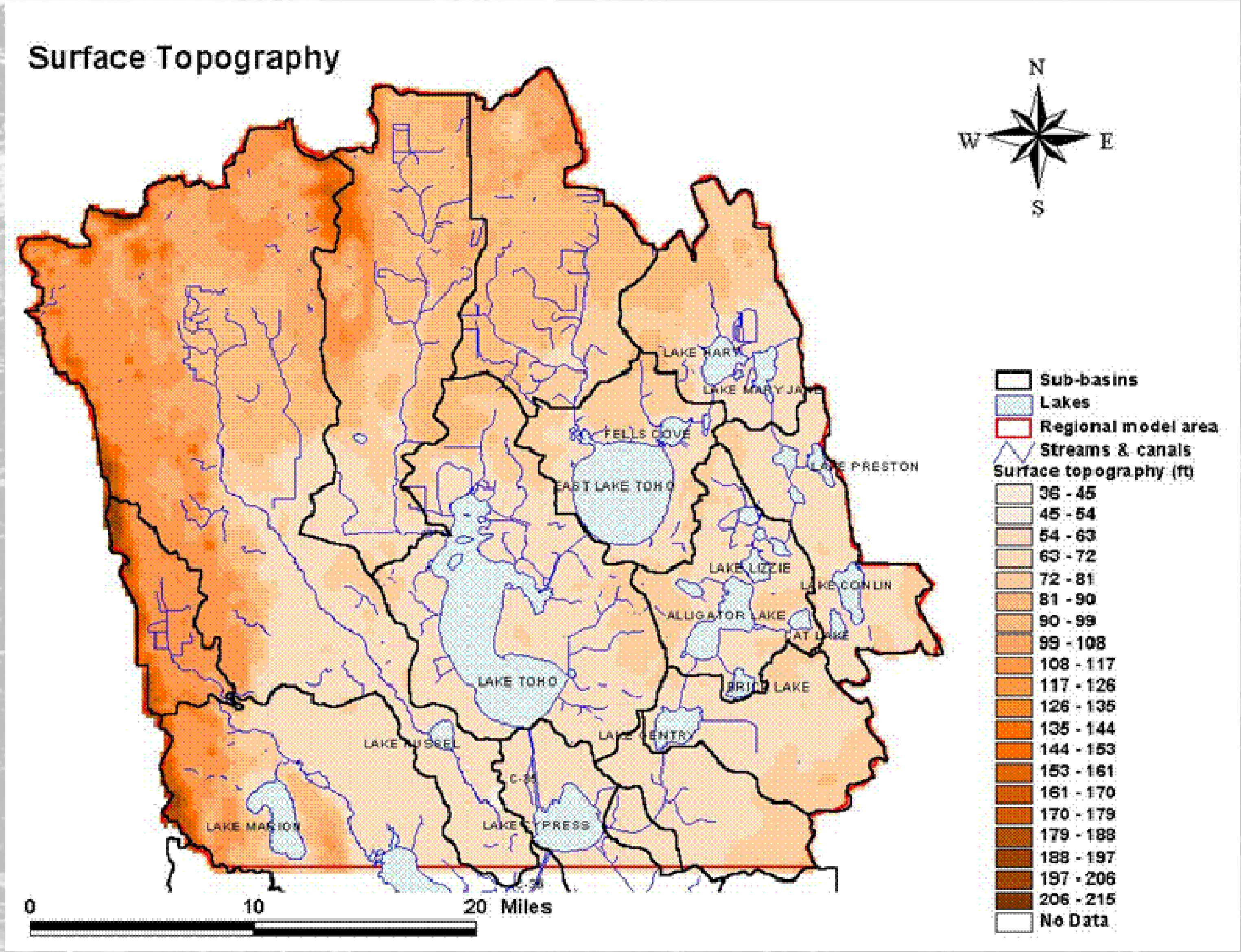


- 1 layer (floridan as ghb)
- 1000x1000 ft (approx 30000 cells)
- 2D overland flow
- detailed HD model
- gravity UZ flow (reduced profiles)
- irrigation module
- structure operations

Components used in Lk. Toho model



Surface Topography
(5 ft USGS quad sheets + point information)



Daily rainfall / Thiessen polygons

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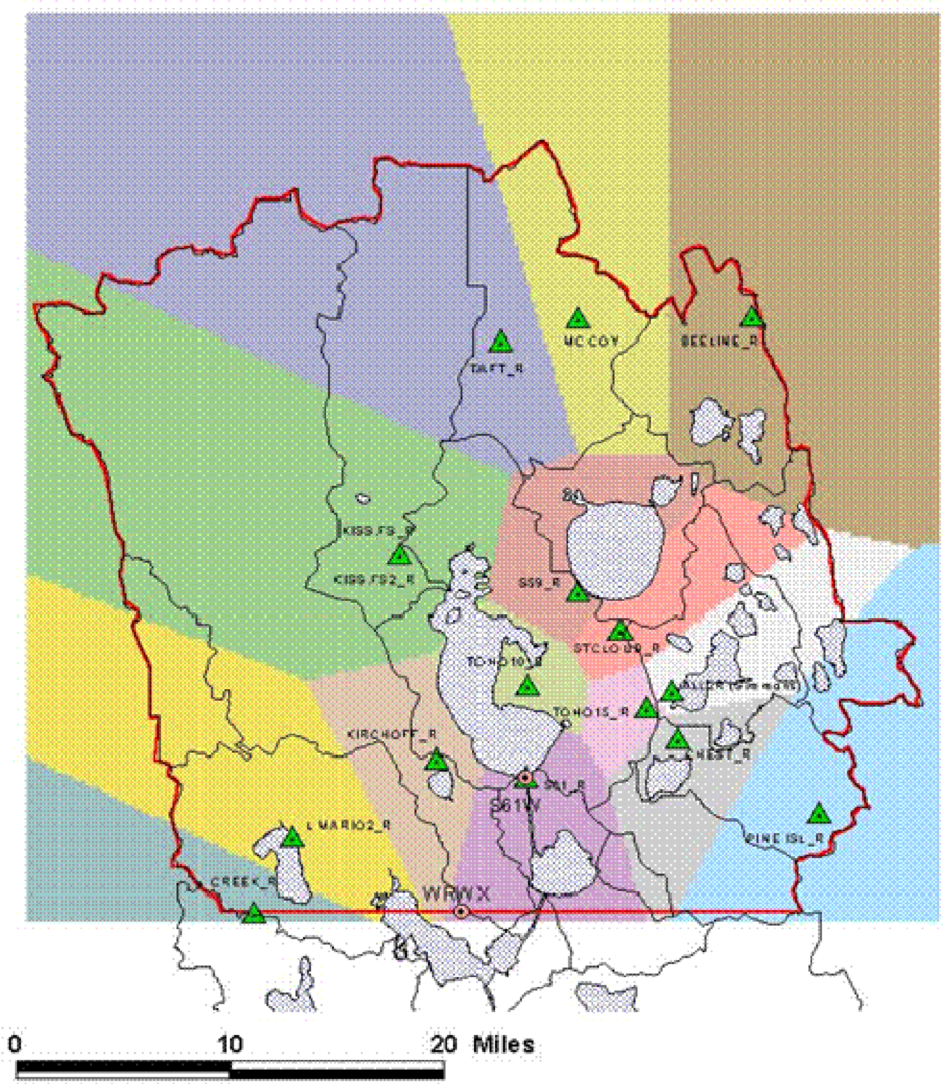
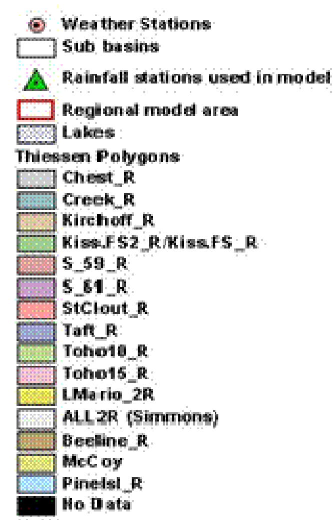
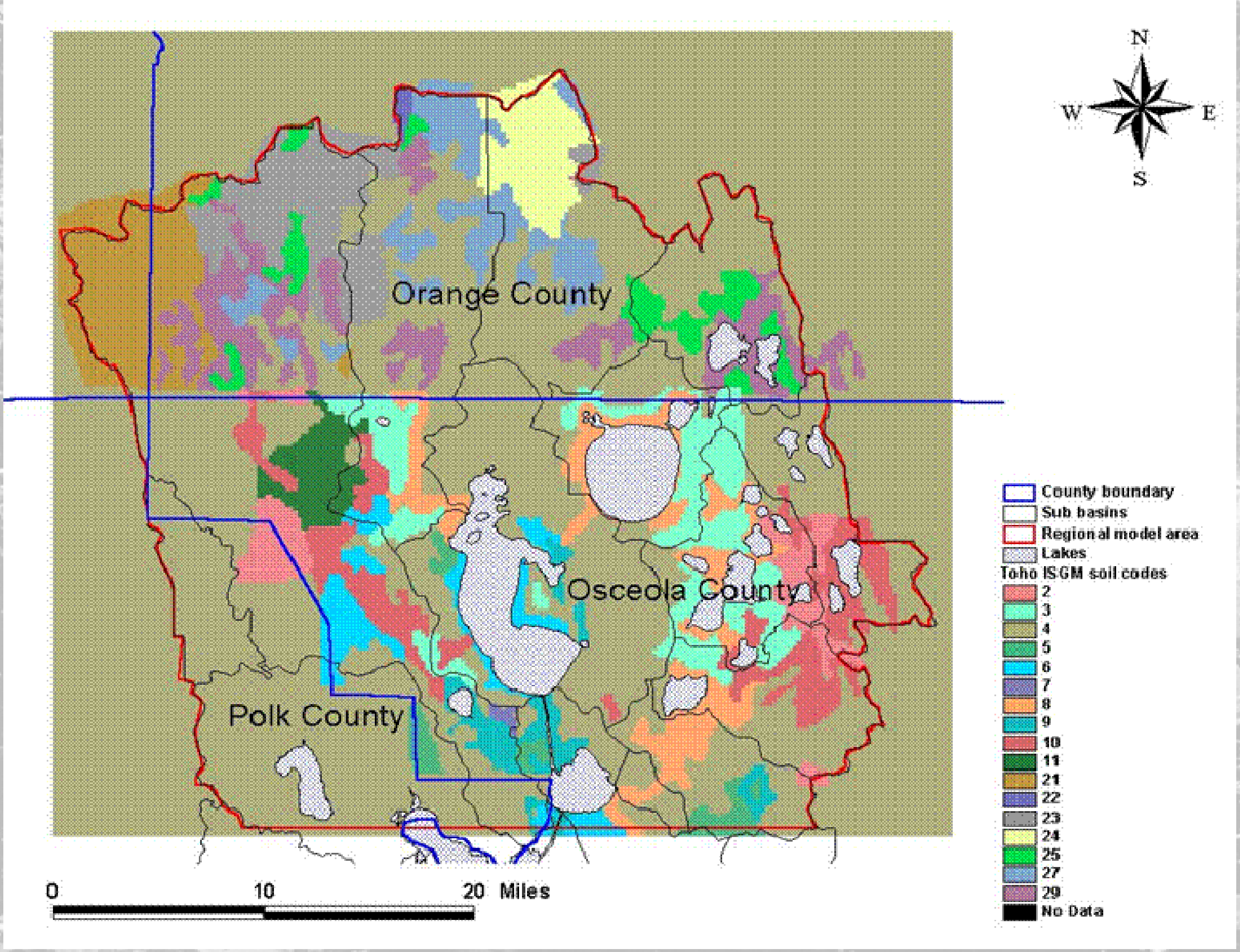
DHI Software



Station ID	Mean Rainfall (1997-2000)		
	inch/day	inch/year	mm/year
CHEST_R_H6070	0.141	51.510	1308.354
CREEK_R_05841	0.148	53.960	1370.584
KIRCHOFF_R_05862	0.132	48.100	1221.740
KISS.FS_R_06305	0.155	56.650	1438.910
S59_R_16567	0.131	47.690	1211.326
S61_R_05868	0.150	54.600	1386.840
S61_R_16570	0.141	51.510	1308.354
SHING.RG_15323	0.146	53.240	1352.296
STCLOUD_R_16619	0.184	67.260	1708.404
TAFT_R_06042	0.149	54.290	1378.966
TOHO10_R_JW234	0.146	53.330	1354.582
TOHO15_R_JW235	0.183	66.850	1697.990
L_MARIO2_R_05884	0.177	64.560	1639.824
ALL2R_HA469	0.183	66.850	1697.990
BEELINE_R_05963	0.166	60.410	1534.414
MC_COY_16634	0.180	65.570	1665.478
PINE_ISL_R_05876	0.155	56.530	1435.862
KISS.FS2	0.165	60.300	1531.620

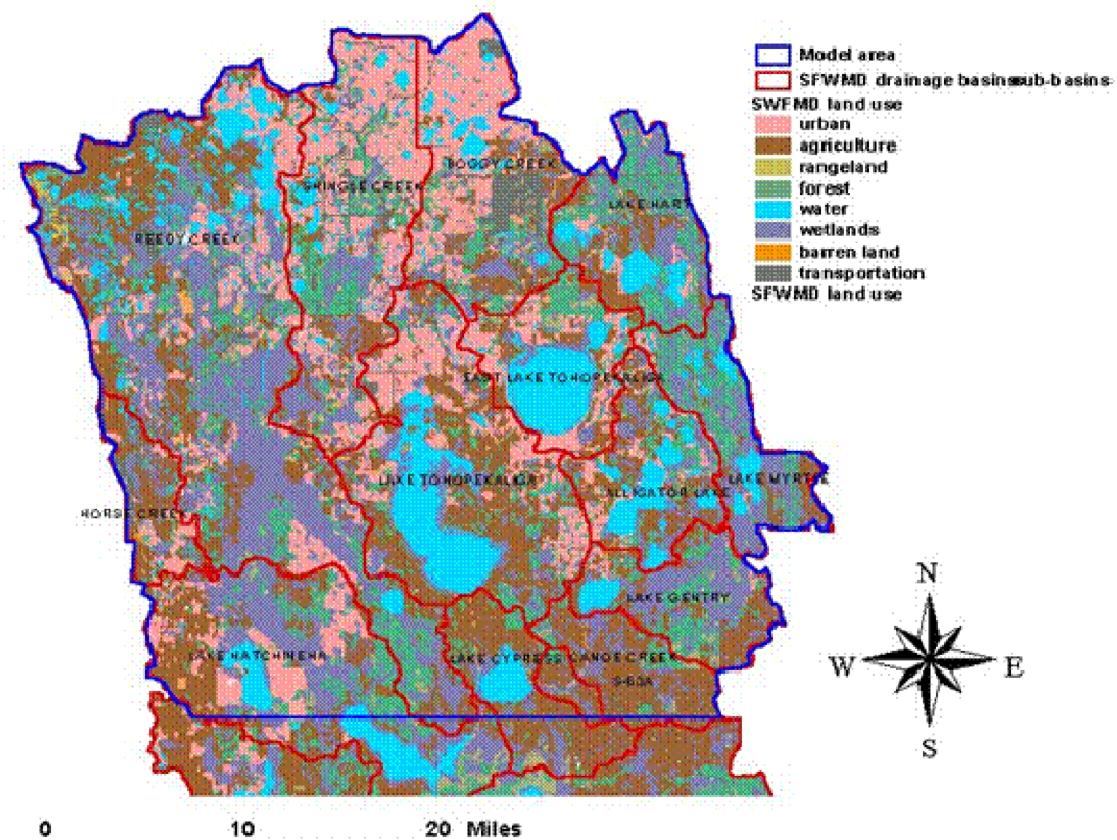


Soil Map used to distributed UZ soil profiles



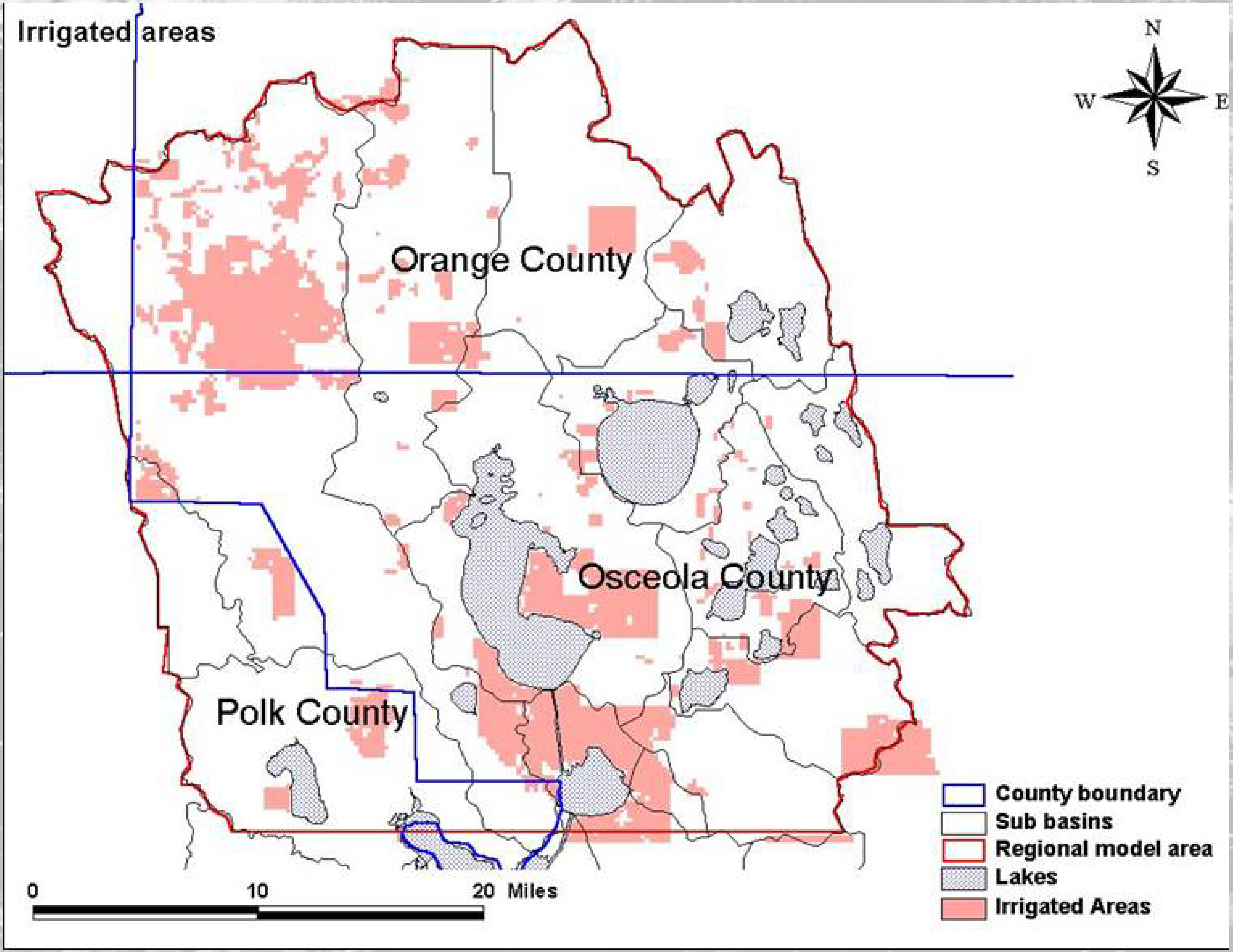
Land-use map used to distribute vegetation types

Land use

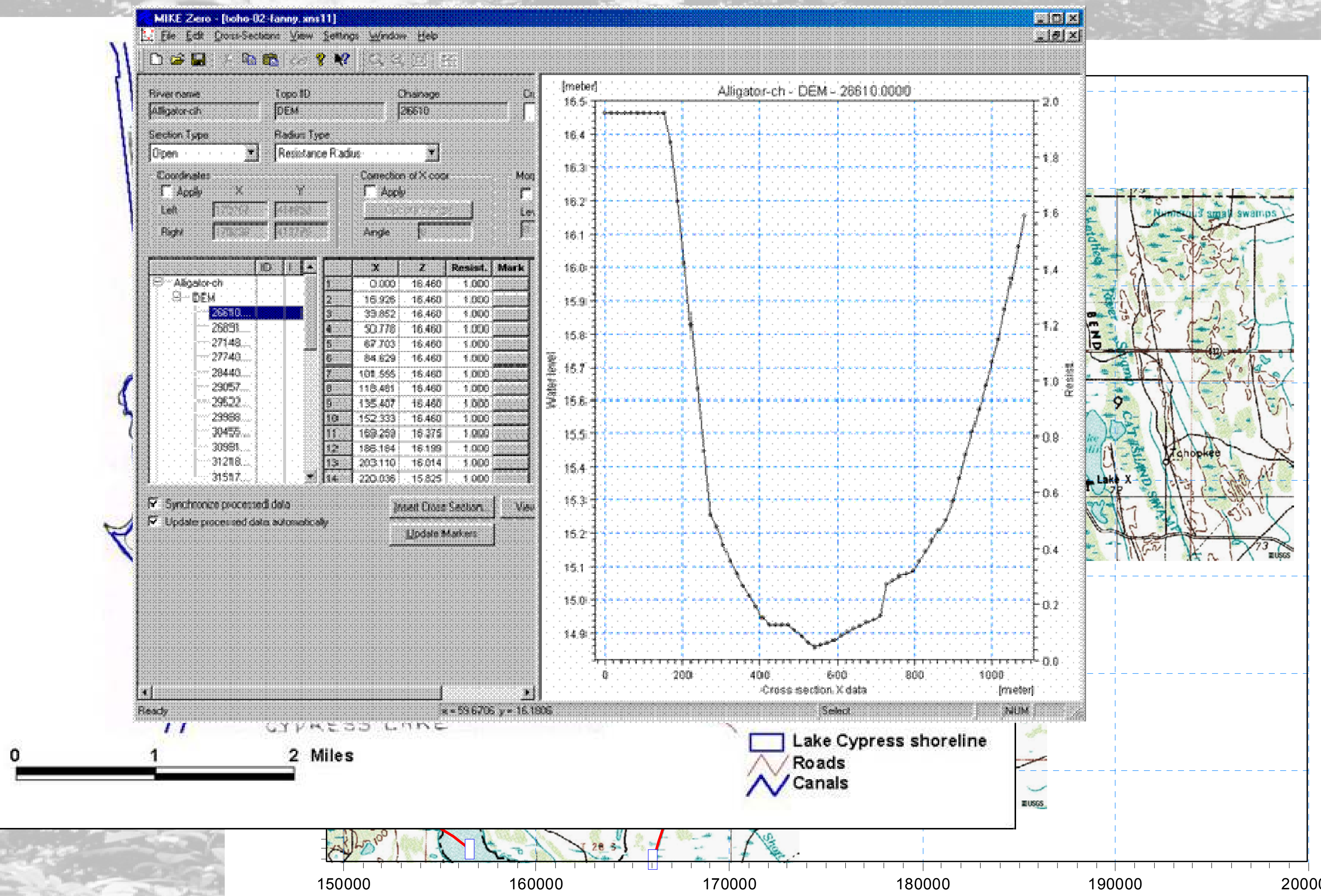


LAND USE		Area	
level 2	Text	(sq. miles)	%
100	URBAN AND BUILT-UP	168.0	16%
110	Residential, low density	44.8	4%
120	Residential, Medium density	37.3	4%
130	Residential, High density	25.3	2%
140	Commercial and Services	14.9	1%
150	Industrial	11.8	1%
160	Extractive	1.9	0%
170	Institutional	3.6	0%
180	Recreational	12.2	1%
190	Open Land	16.3	2%
200	AGRICULTURE	284.2	27%
210	Cropland and pastureland	182.9	18%
220	Tree crops	75.2	7%
240	Nurseries and vineyards	6.8	1%
250	Specialty farms	0.6	0%
260	Other open lands rural	18.8	2%
300	RANGELAND	11.8	1%
310	Herbaceous	0.3	0%
320	Shrub and Brushland	5.4	1%
330	Mixed Rangeland	6.0	1%
400	UPLAND FORESTS	144.6	14%
410	Coniferous forest	94.6	9%
420	Hardwood forest	12.4	1%
430	Hardwood forest, continued	35.6	3%
440	Tree plantations	1.9	0%
500	Water	122.0	12%
510	Streams and waterways	1.9	0%
520	Lakes	113.3	11%
530	Reservoirs	6.8	1%
540	Bays and Estuaries	0.0	0%
560	Slough waters	0.0	0%
600	Wetlands	260.8	25%
610	Hardwood Forests	90.1	9%
620	Coniferous forest	64.9	6%
630	Forested mixed	65.9	6%
640	non-forested wetlands	39.9	4%
650	non-vegetated	0.0	0%
700	Barren land	11.8	1%
710	Beaches	0.0	0%
720	sand other than beaches	0.1	0%
740	disturbed land	11.7	1%
800	TRANSPORTATION & UTILITIES	32.8	3%
810	Transportation	25.3	2%
820	Communication	0.1	0%
830	Utilities	7.4	1%

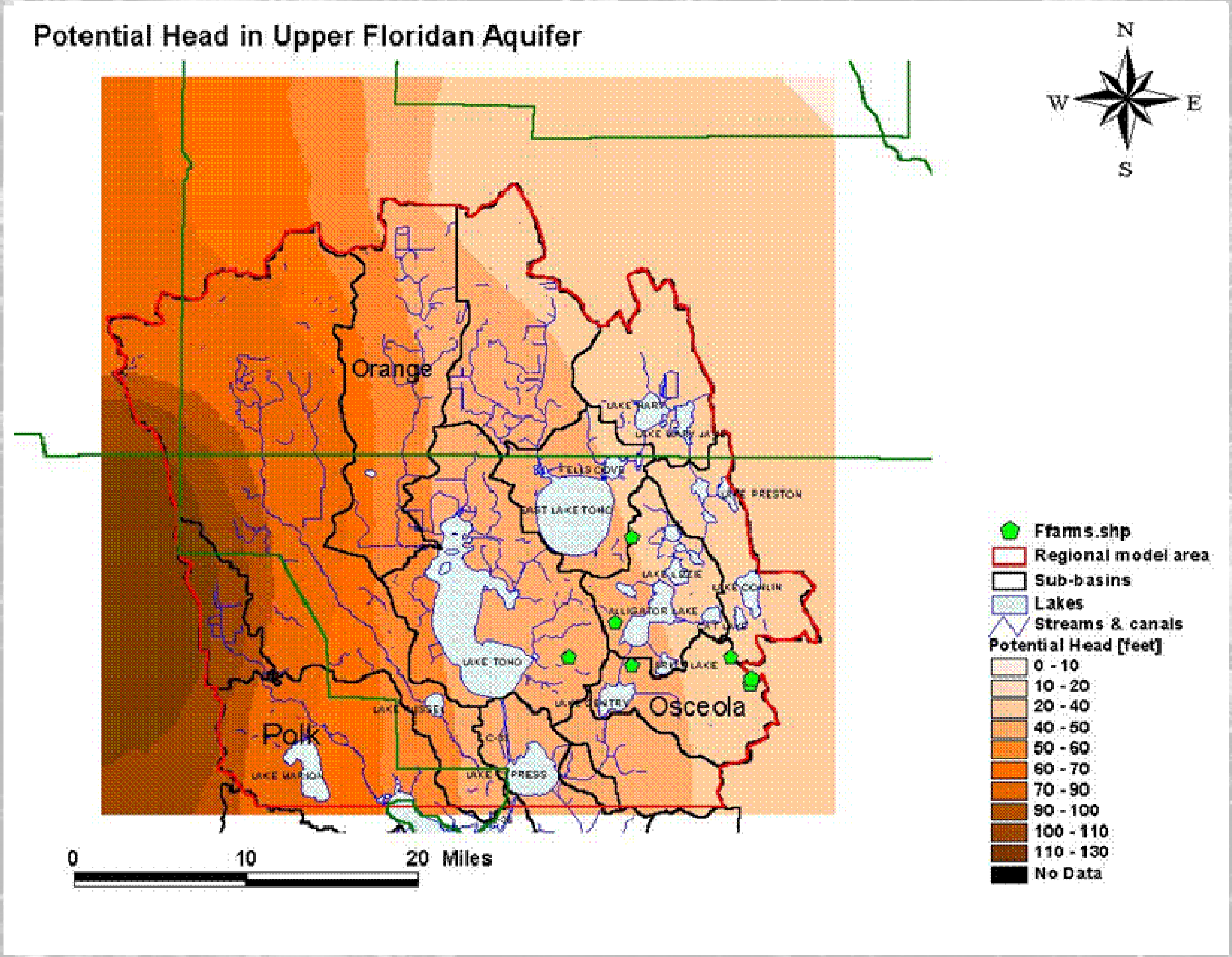
Irrigated areas – MIKE SHE IR applied



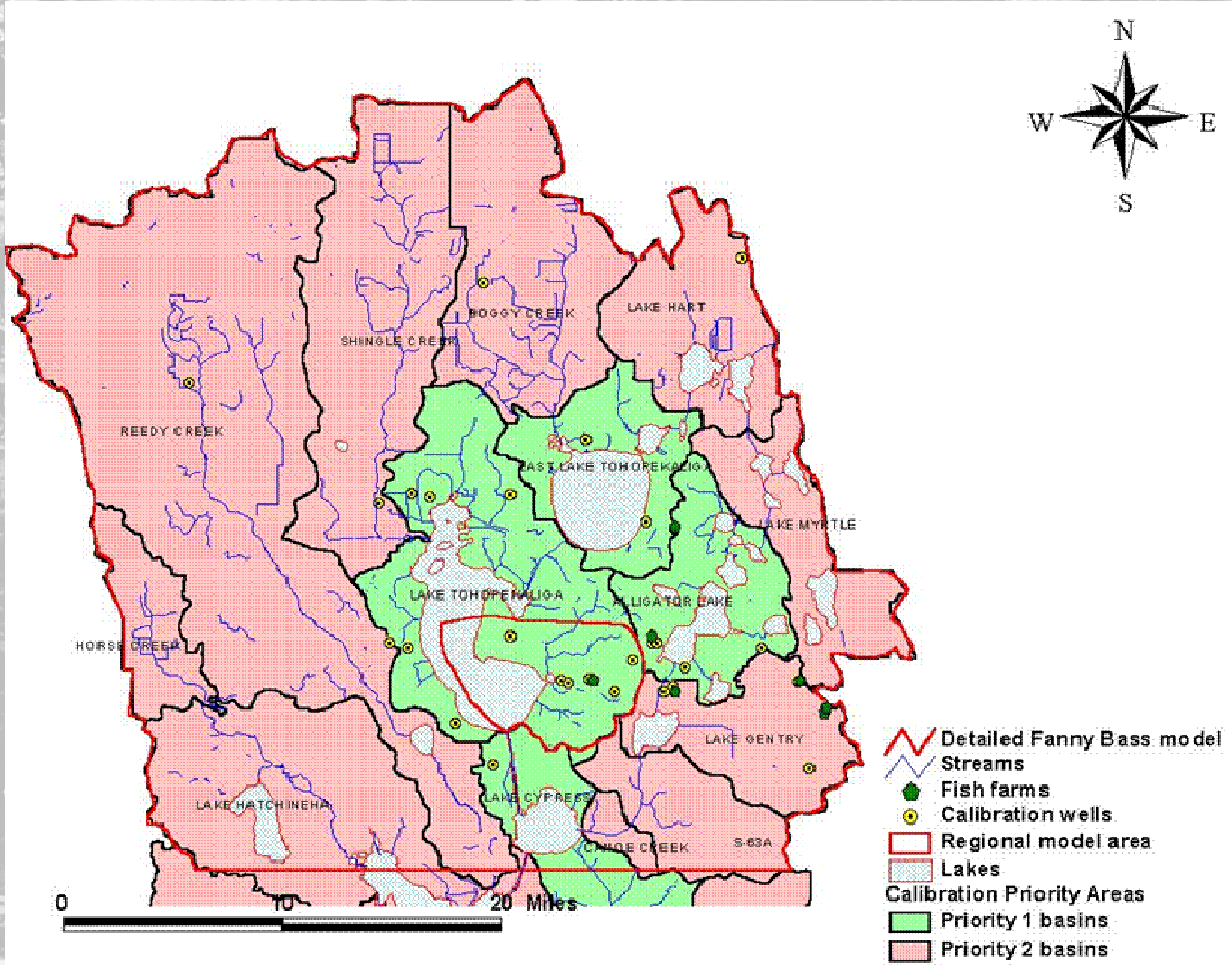
Hydraulic model MIKE11 with lakes and creeks



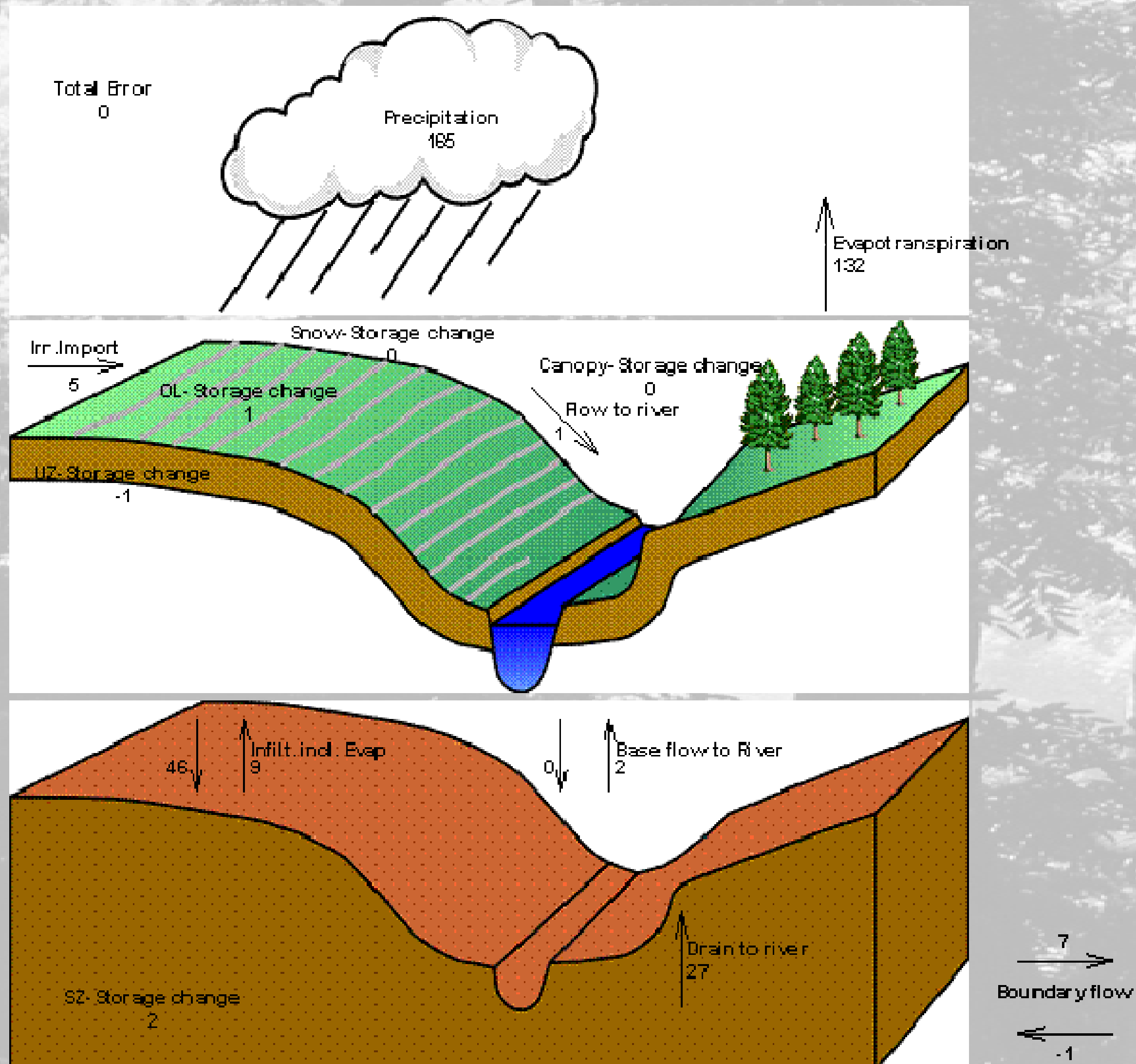
Geological Profiles (GeoEditor)



Priority 1 and 2 areas for calibration/validation

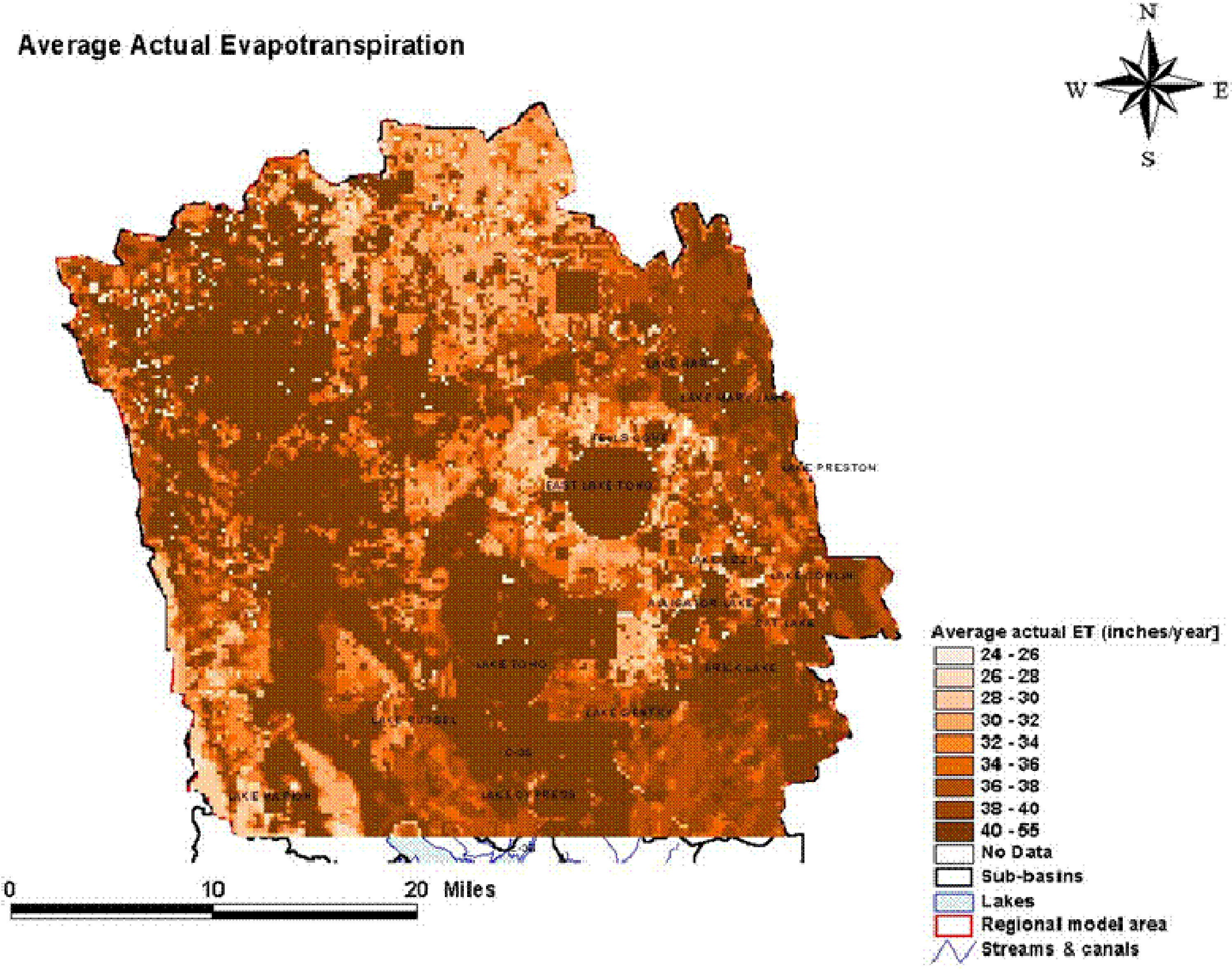


Basin water budget

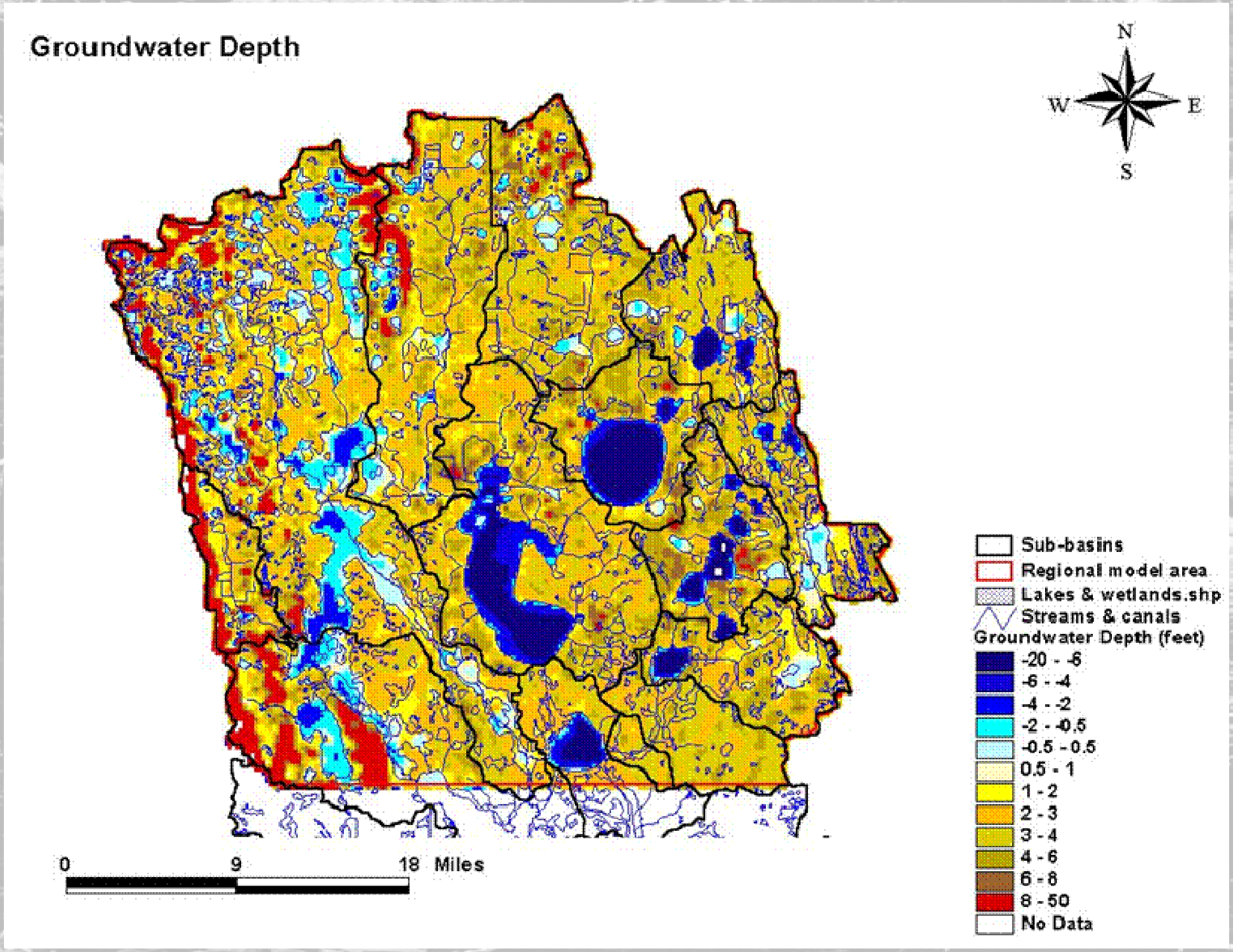


Waterbalance accumulated from 6/22/87 to 10/4/00
Flow Result File : Toho-1000ft-11x.frf
Title : Lk Toho   Text : Regional Model

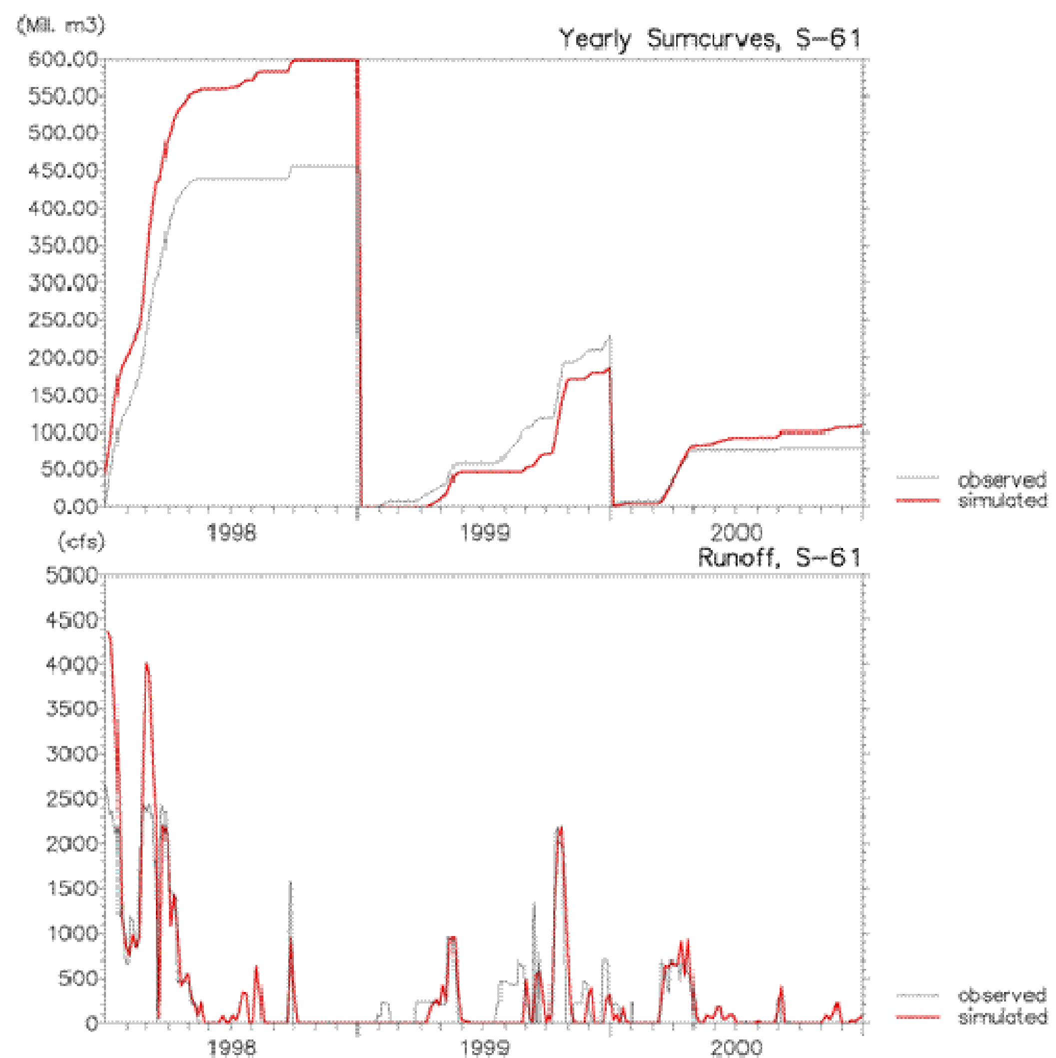
Actual Evapotranspiration (basin average 39 inch/year)



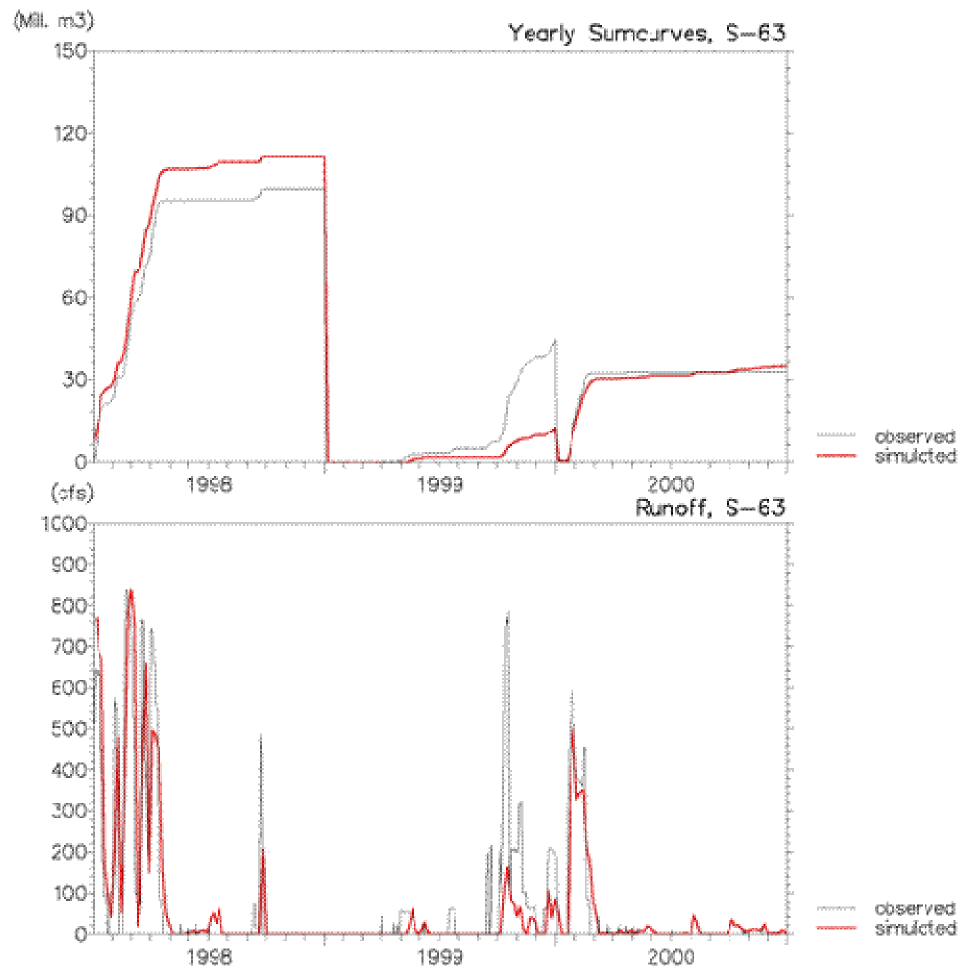
Groundwater Depth



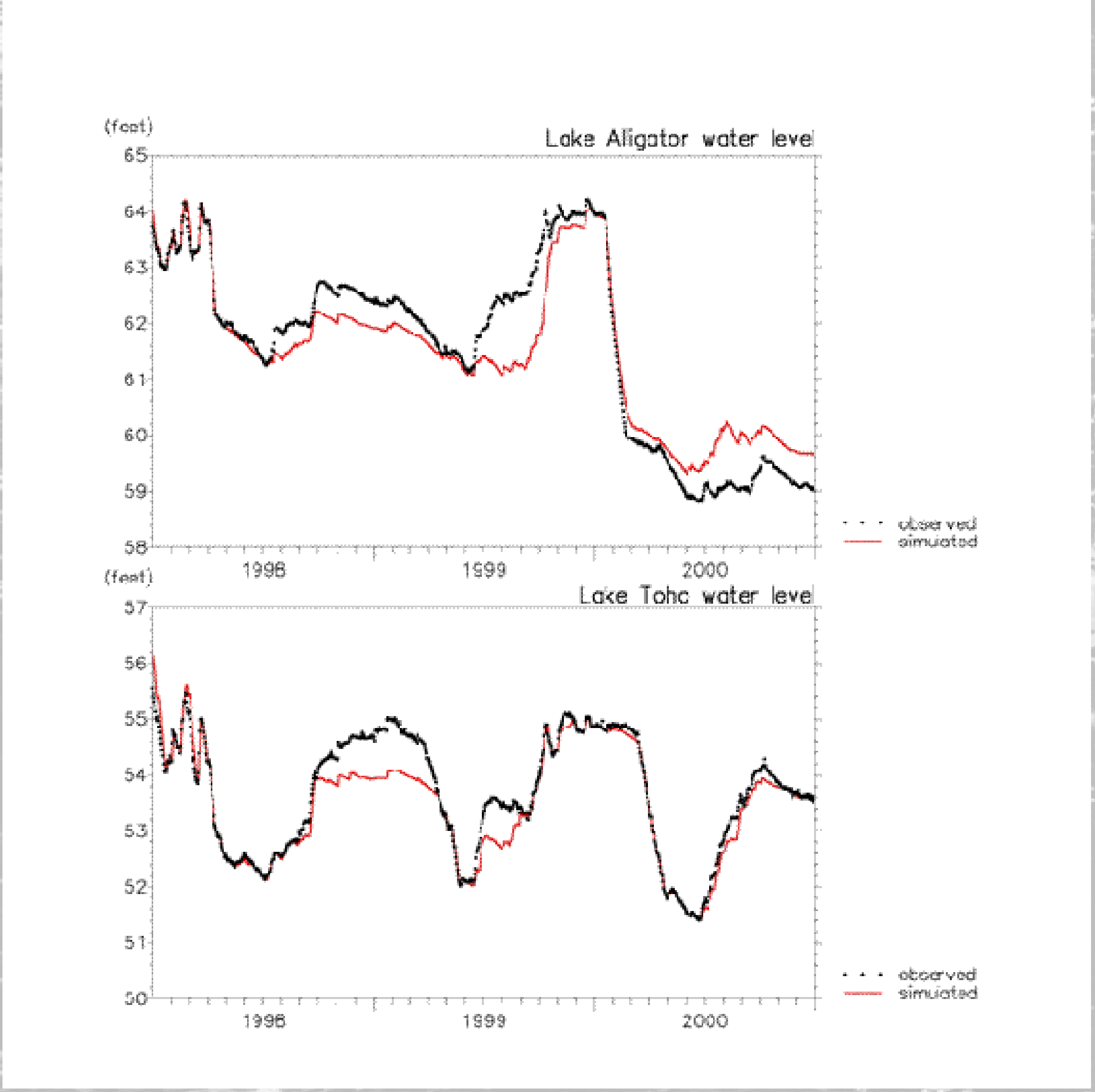
Simulated and observed runoff at S-61 (Lk. Toho)



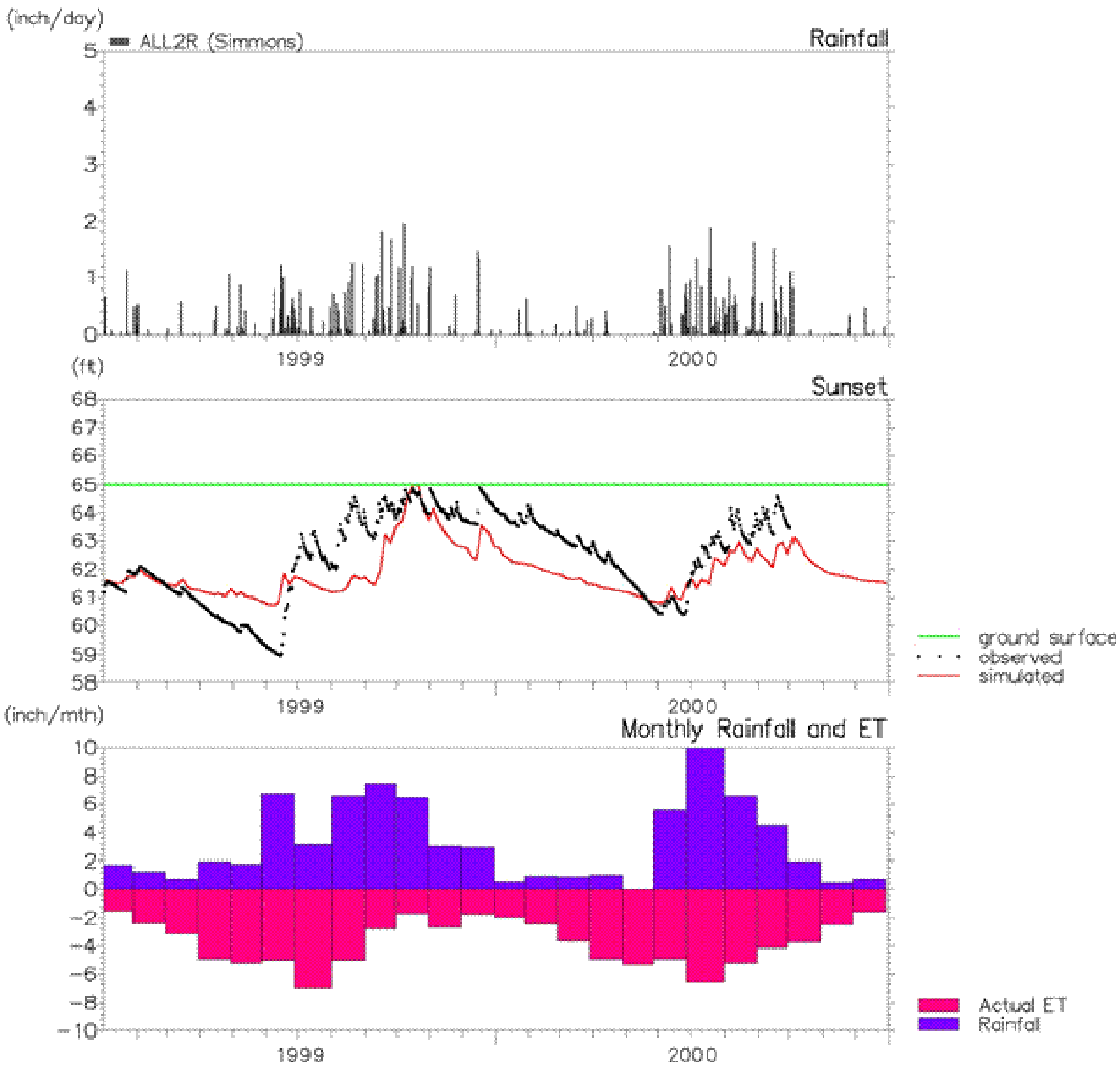
Simulated runoff at Lk. Gentry (Calibration)

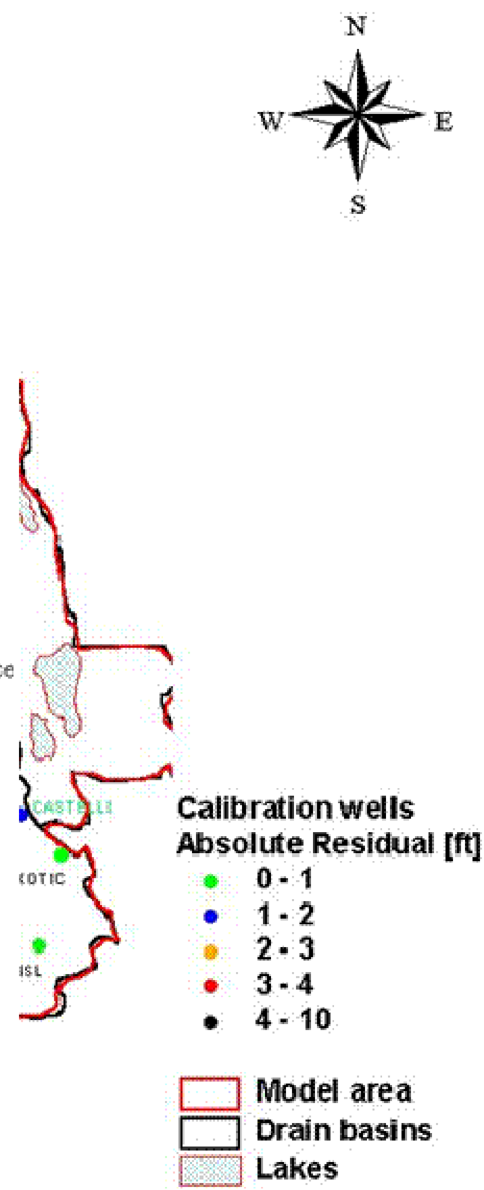


Water Level in Lk. Alligator and Lk. Toho (Calibration)

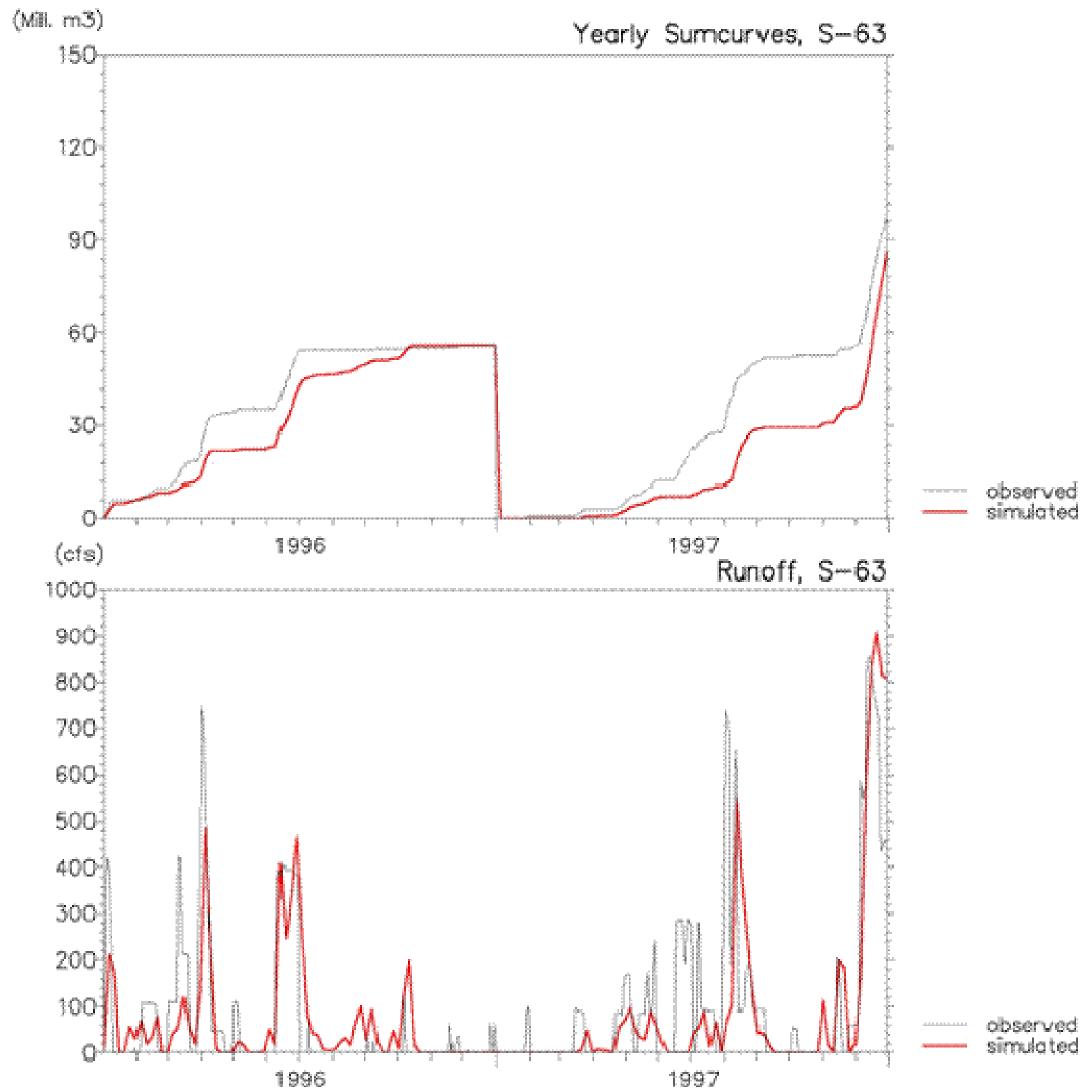


Overall Groundwater Calibration





Validation (split sample)



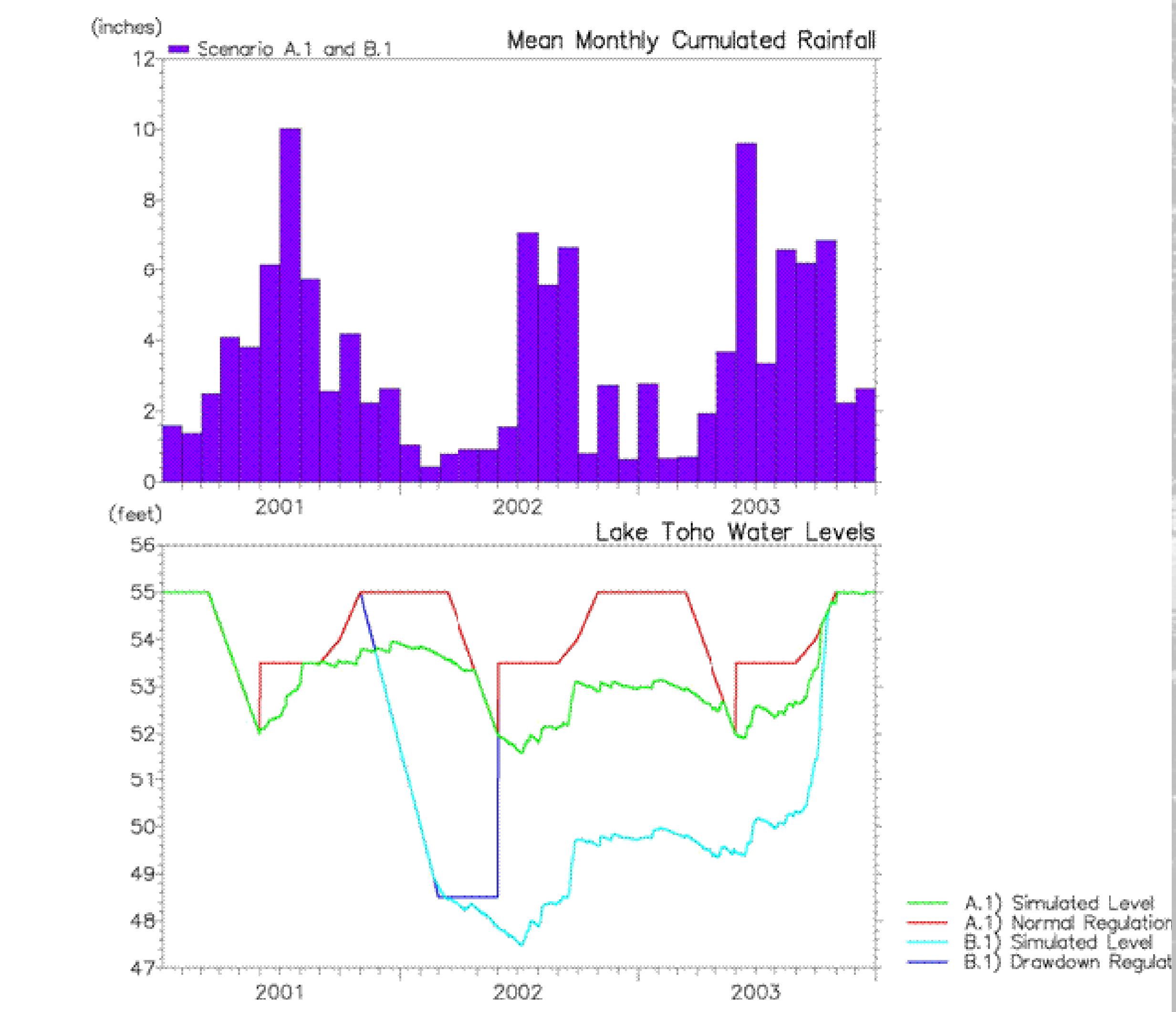
DHI WATER & ENVIRONMENT

Scenarios

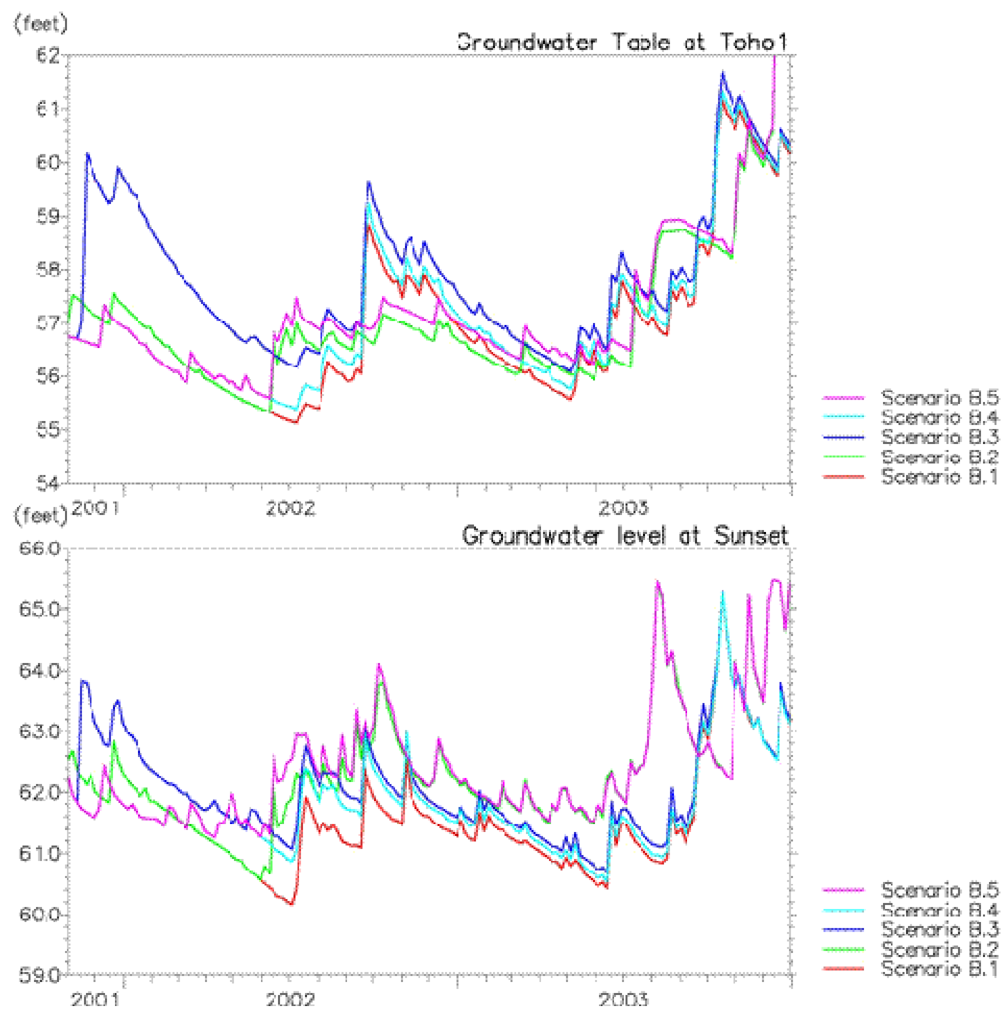
	Normal Regulation (warm up)		Normal Regulation		Normal Regulation	
A. Normal Regulation	START	END	START	END	START	END
	01-Nov-00	01-Nov-01	01-Nov-01	31-May-02	01-Jun-02	31-Dec-03
	Meteorological data used for scenarios					
A.1 (normal/drought/drought)	01-Nov-96	31-Oct-97	01-Nov-99	31-May-00	01-Jun-98	31-Dec-99
A.2 (normal/drought/normal)	01-Nov-96	31-Oct-97	01-Nov-99	31-May-00	01-Jun-96	31-Dec-97
A.3 (normal/wet/drought)	01-Nov-96	31-Oct-97	01-Nov-94	31-May-95	01-Jun-98	31-Dec-99
A.4 (normal/normal/drought)	01-Nov-96	31-Oct-97	01-Nov-96	31-May-97	01-Jun-98	31-Dec-99
A.5 (normal/normal/normal)	01-Nov-96	31-Oct-97	01-Nov-96	31-May-97	01-Jun-96	31-Dec-97

	Normal Regulation (warm up)		Drawdown		Refill	
B. Drawdown	START	END	START	END	START	END
	01-Nov-00	01-Nov-01	01-Nov-01	31-May-02	01-Jun-02	31-Dec-03
	Meteorological data used for scenarios					
B.1 (normal/drought/drought)	01-Nov-96	31-Oct-97	01-Nov-99	31-May-00	01-Jun-98	31-Dec-99
B.2 (normal/drought/normal)	01-Nov-96	31-Oct-97	01-Nov-99	31-May-00	01-Jun-96	31-Dec-97
B.3 (normal/wet/drought)	01-Nov-96	31-Oct-97	01-Nov-94	31-May-95	01-Jun-98	31-Dec-99
B.4 (normal/normal/drought)	01-Nov-96	31-Oct-97	01-Nov-96	31-May-97	01-Jun-98	31-Dec-99
B.5 (normal/normal/normal)	01-Nov-96	31-Oct-97	01-Nov-96	31-May-97	01-Jun-96	31-Dec-97

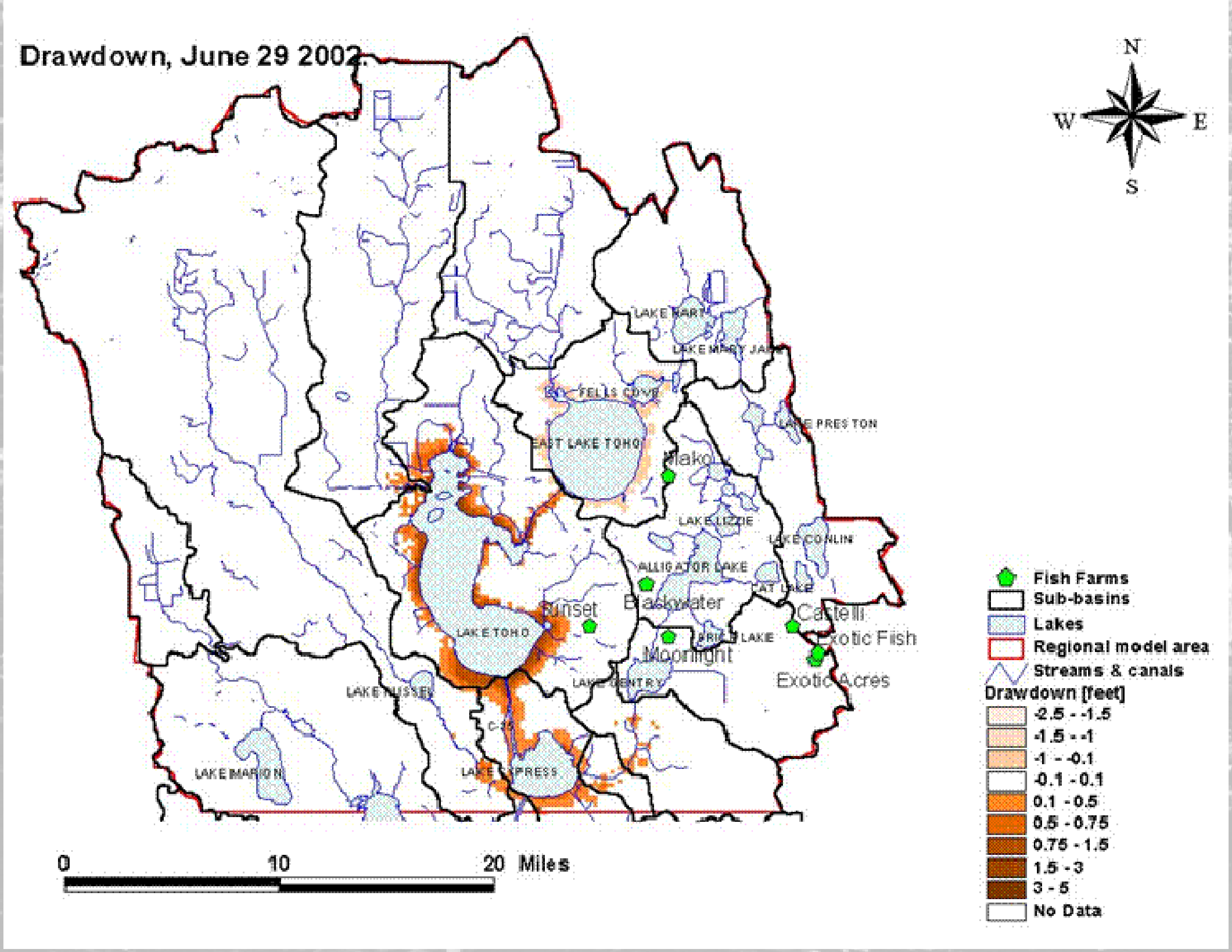
Drawdown scenario (A1-B1, worst case)



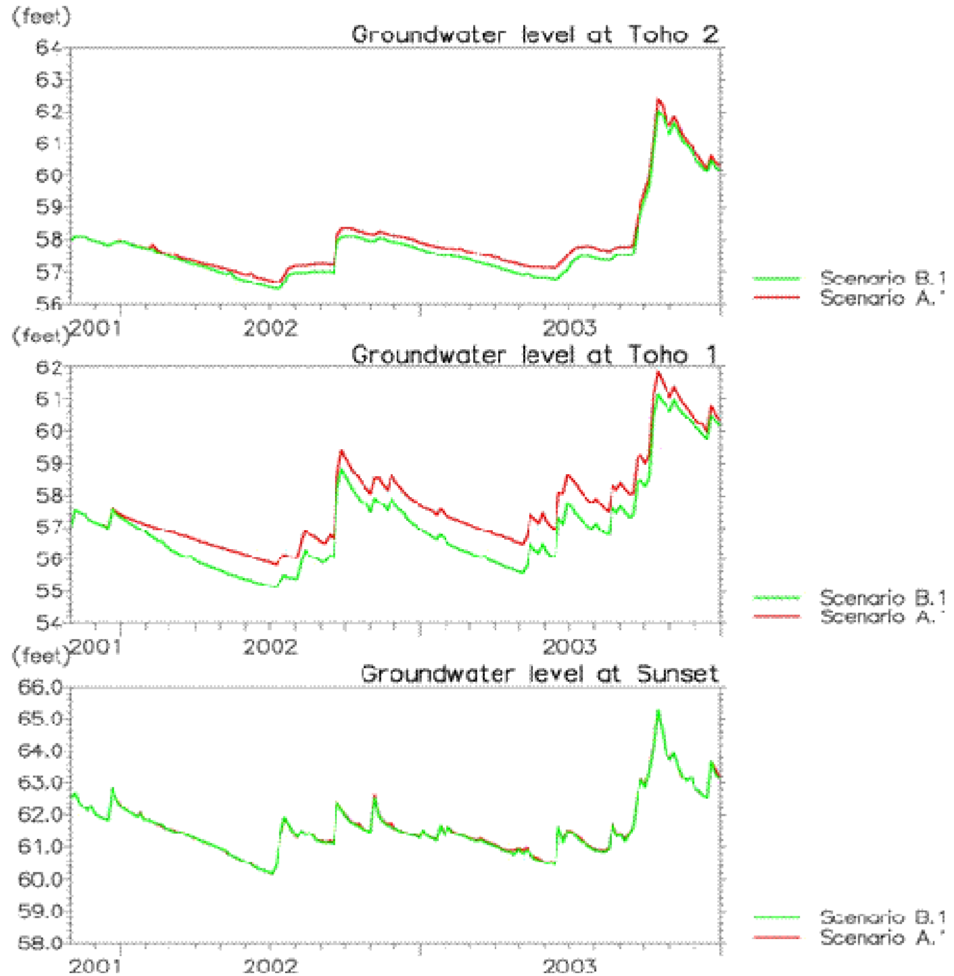
Differences caused by climate



Maximum impact map



Impact of drawdown (worst case)



Upper Kissimmee model run-times

- **Runtimes (old Lk. Toho model approx 1 hour/year on a 700 MHz computer**
- **revised (simple UZ) model runs 11.5 minutes/year on my 1.3 Gb Laptop**
- **can be tuned further by removing points from the hydraulic model**
- **simple LR model will reduce run-times further (only flow modeling not gw !)**

What could be done

- Approach and spatial/temporal scaling in the upper Kissimmee model Ok for entire basin
- update existing upper Kissimmee model (1-2 man-weeks) – some adjustment of calibration
- Get started with the lower basin – could run in parallel (i.e. two models and then merge the models later on (target sim. Execution times 20-40 minutes/year
- Consider building a screening model (LR based) link to MIKE BASIN / UKISS ?
- Automatic calibration / sensitivity analysis (AUTOCAL)
- Validate
- Could be done in 6-8 months

Why use MIKE SHE for KB ?

- **MIKE SHE meets all the requirements for the KB project and a good model for the upper Kissimmee model already exists.**
- **MIKE11 is the best hydraulic model in the world and meets all proj. objectives**
- **MIKE SHE is flexible – it allows you to use an evolving approach (simple through complex/advanced)**
- **MIKE SHE is operational - it has been used for many different applications all over the world.**
- **MIKE SHE includes tools and a GUI that saves you time**
- **MIKE SHE is proven and accepted and is the best tested integrated model on the market.**
- **It´s a safe choice that would bring the project safely to harbour.**

DHI Software

DHI WATER & ENVIRONMENT

MIKE SHE is bridging the gap …

Advanced

Simple

Useful